US010249807B2

(12) United States Patent
Bierhuizen et al.

(10) **Patent No.: US 10,249,807 B2**
(45) **Date of Patent: Apr. 2, 2019**

(54) **PRE-ROTATED OVERMOULDED BIDIRECTIONAL SPREADING LENS FOR STRETCHED LEADFRAME ARCHITECTURE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **16/005,299**

(22) Filed: **Jun. 11, 2018**

(65) **Prior Publication Data**

US 2018/0358525 A1 Dec. 13, 2018

Related U.S. Application Data

(63) Continuation of application No. 14/387,868, filed as application No. PCT/IB2013/052429 on Mar. 27, 2013, now Pat. No. 9,997,684.

(Continued)

(51) **Int. Cl.**
H01L 33/62 (2010.01)
F21K 9/90 (2016.01)

(Continued)

(52) **U.S. Cl.**
CPC ***H01L 33/62*** (2013.01); ***F21K 9/27*** (2016.08); ***F21K 9/90*** (2013.01); ***H01L 25/13*** (2013.01);

(Continued)

(58) **Field of Classification Search**
CPC ... F21K 9/17; F21K 9/90; H01L 33/62; H01L 33/60; H01L 25/13; H01L 33/005;

(Continued)

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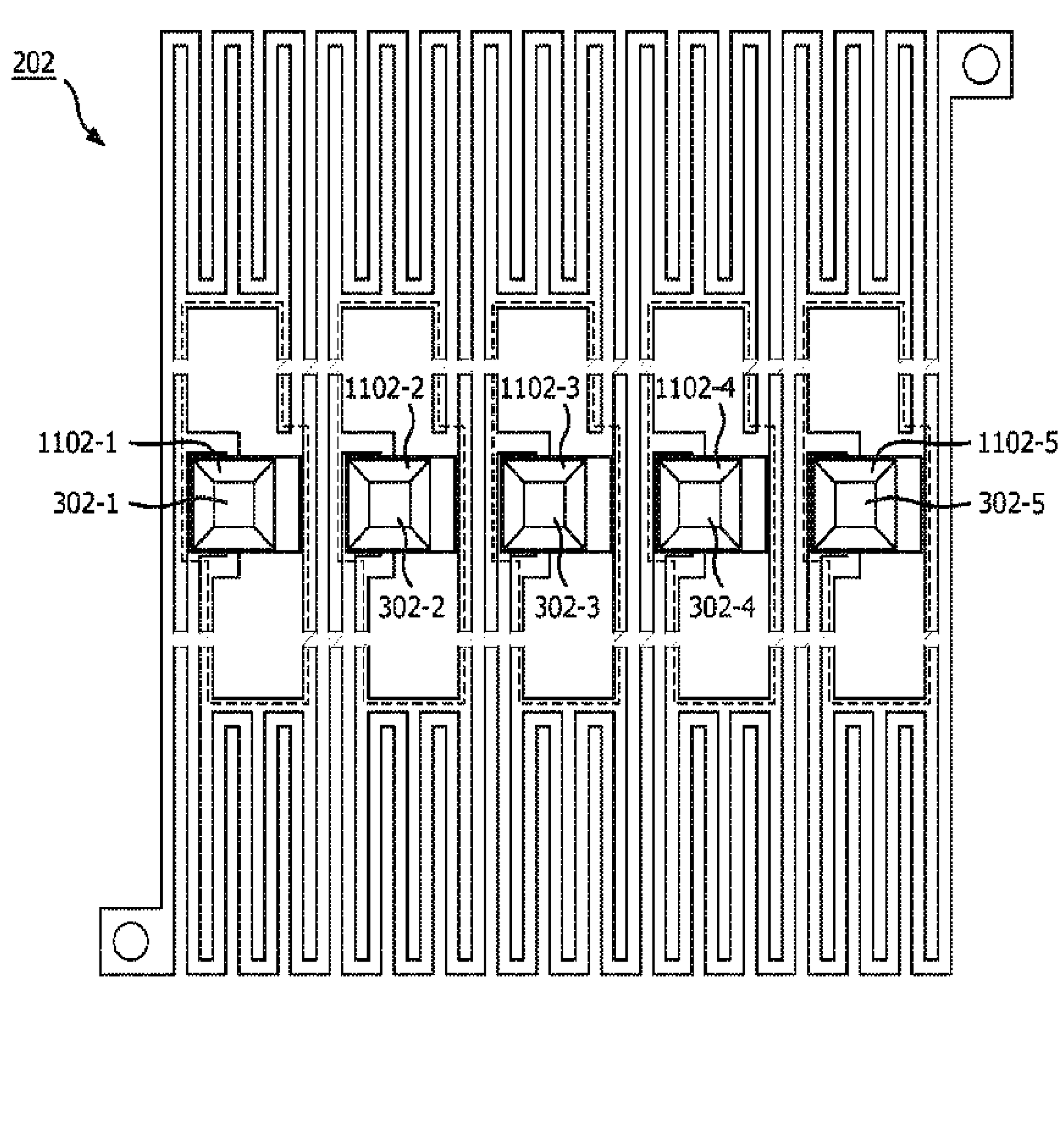
(57) **ABSTRACT**

A solid state light-emitting device (LED) lighting apparatus comprising a leadframe assembly comprising leadframes spaced apart at a pitch, each leadframe comprising at least one pad, interconnects each linking two adjacent leadframes, LEDs mounted on the leadframes, and bidirectional spreading lenses disposed about the LEDs, each bidirectional spreading lens having a spreading axis and a null axis perpendicular to the spreading axis, each bidirectional spreading lens directing more light in opposite directions along the spreading axis than the null axis, the spreading axis being aligned along the length of the stretched leadframe assembly.

11 Claims, 20 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 61/617,689, filed on Mar. 30, 2012.

(51) **Int. Cl.**

F21K 9/27	(2016.01)
H01L 33/60	(2010.01)
H01L 33/58	(2010.01)
H01L 25/13	(2006.01)
H01L 33/00	(2010.01)
F21Y 115/10	(2016.01)
F21Y 103/10	(2016.01)
F21V 7/00	(2006.01)

(52) **U.S. Cl.**
CPC ***H01L 33/005*** (2013.01); ***H01L 33/58*** (2013.01); ***H01L 33/60*** (2013.01); *F21V 7/005* (2013.01); *F21Y 2103/10* (2016.08); *F21Y 2115/10* (2016.08); *H01L 2924/0002* (2013.01); *H01L 2933/0058* (2013.01); *H01L 2933/0066* (2013.01)

(58) **Field of Classification Search**
CPC H01L 33/58; H01L 2933/0058; H01L 2933/0066; H01L 2924/0002; H01L 2924/00; F21V 7/005; F21Y 2101/02; F21Y 2103/003; F21Y 2103/10; F21Y 2115/10
USPC 257/88; 438/27
See application file for complete search history.

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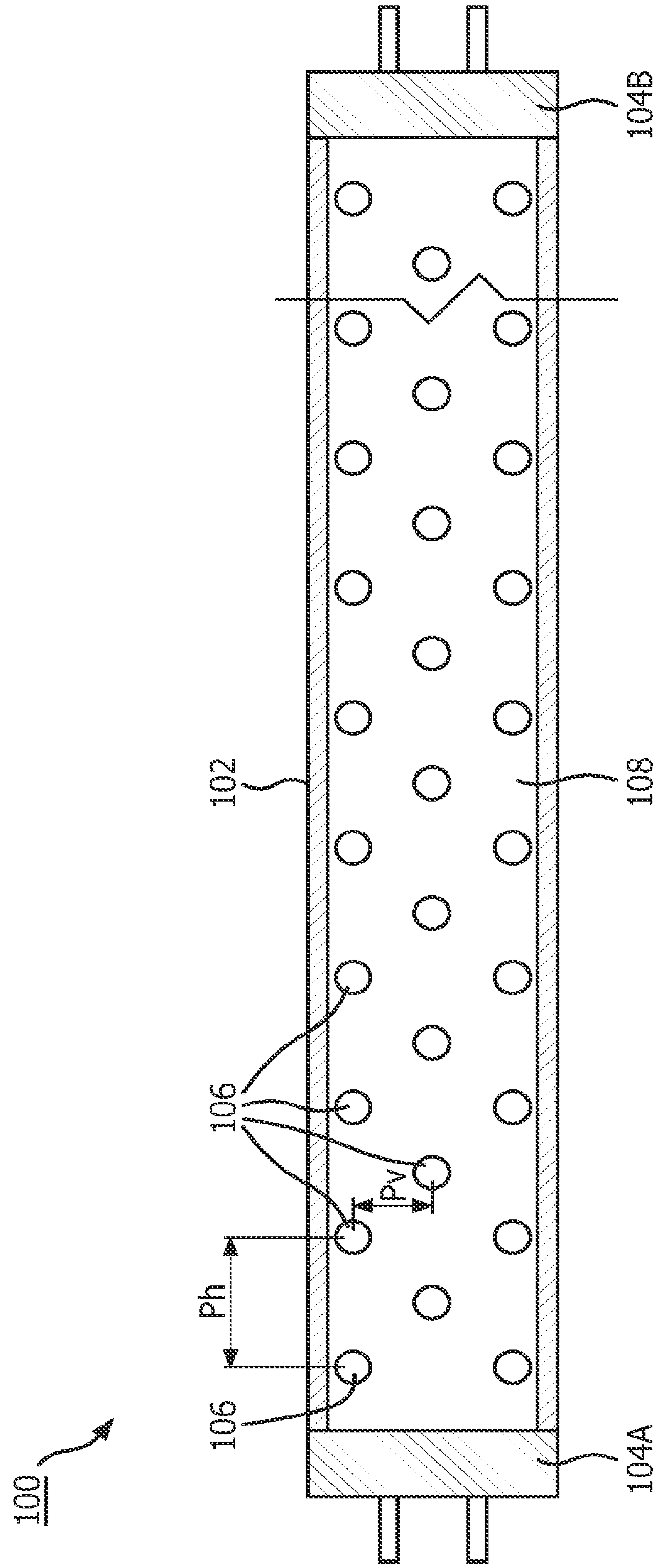
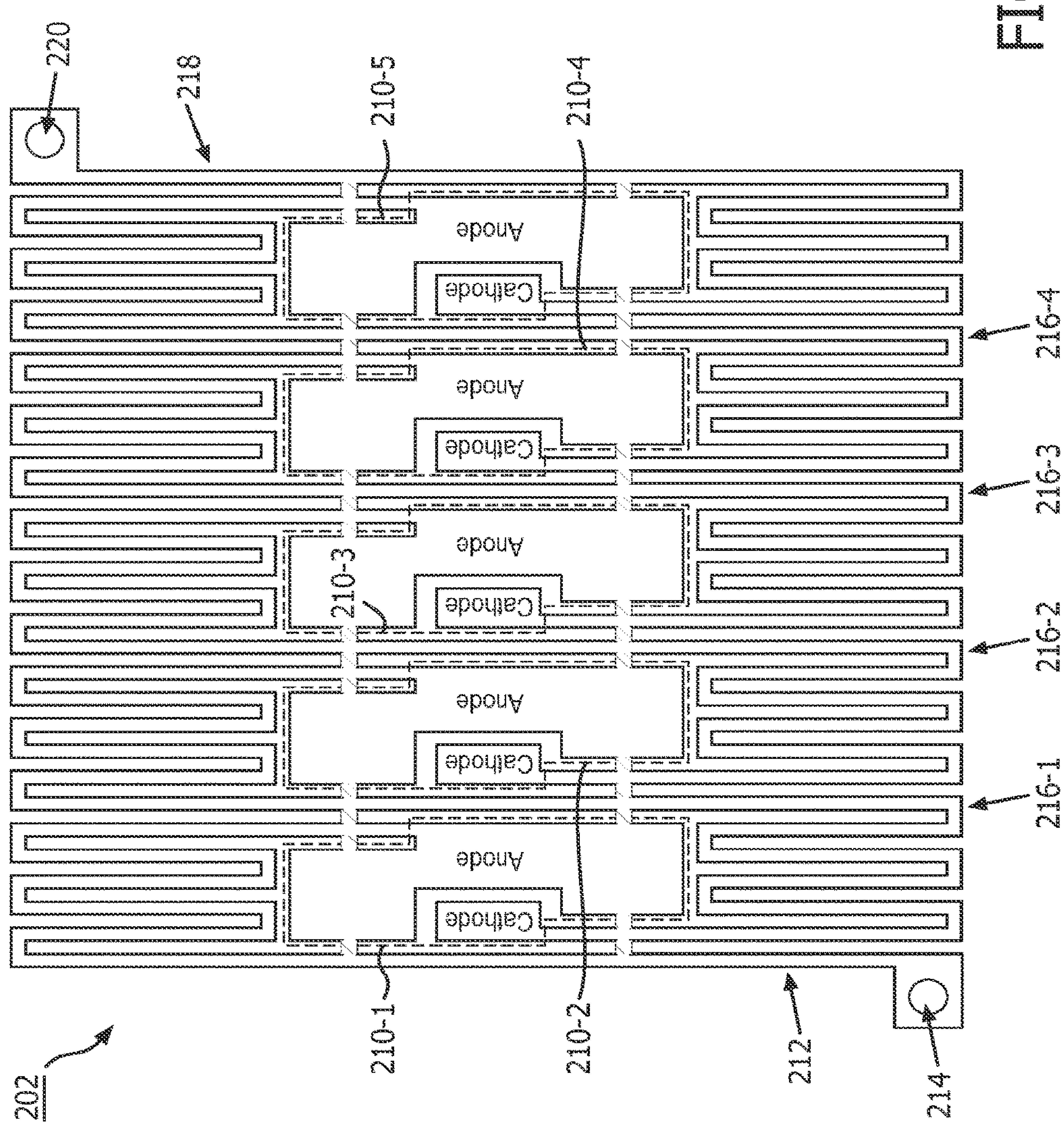
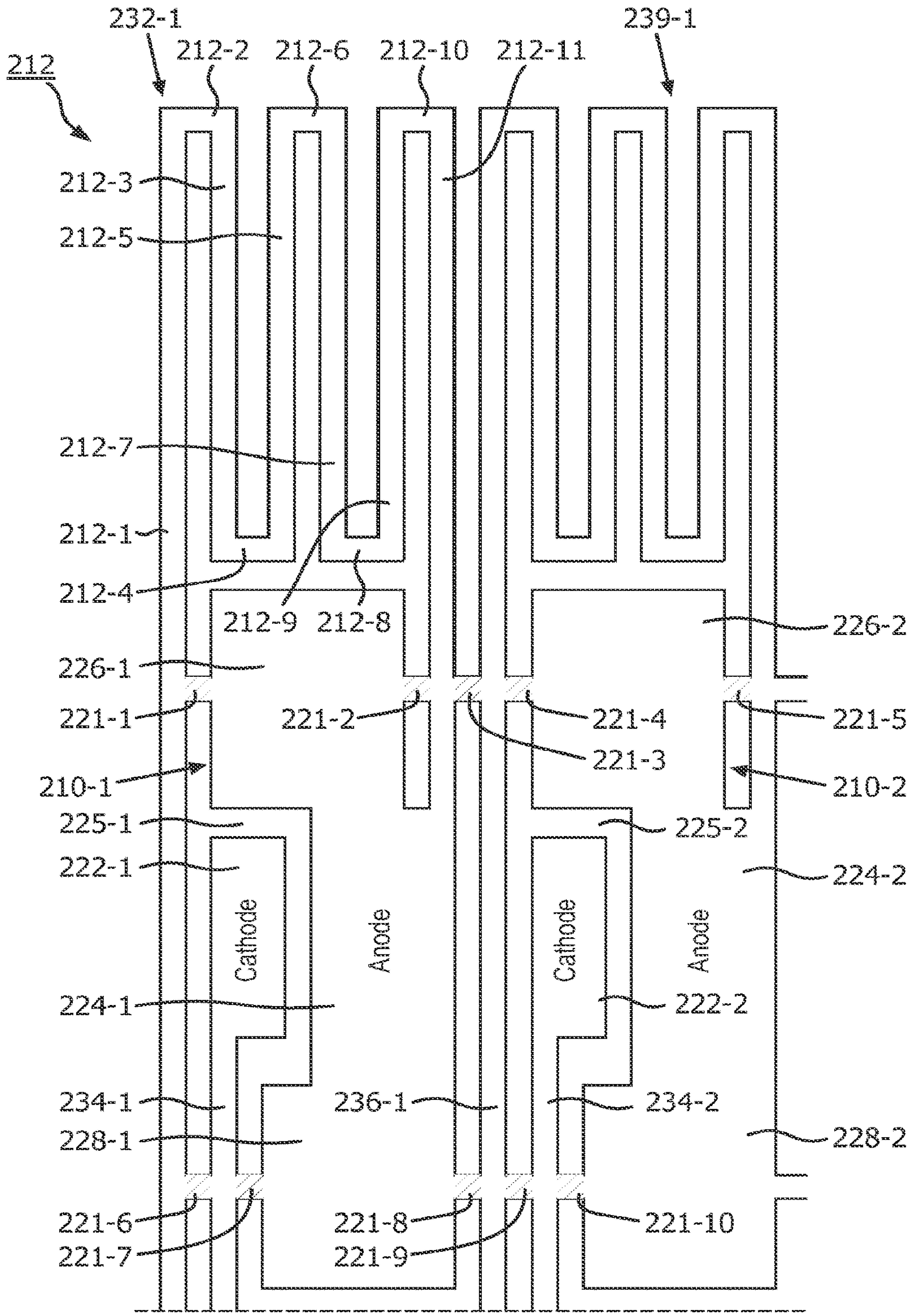


FIG. 1



202
212
214
218
220
210-1
210-2
210-3
210-4
210-5
216-1
216-2
216-3
216-4
Anode
Cathode

FIG. 2A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226-2
226-1
221-1
221-2
221-4
221-5
221-3
210-1
210-2
225-1
225-2
222-1
224-2
Cathode
Anode
Cathode
Anode
224-1
222-2
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234-2
228-1
228-2
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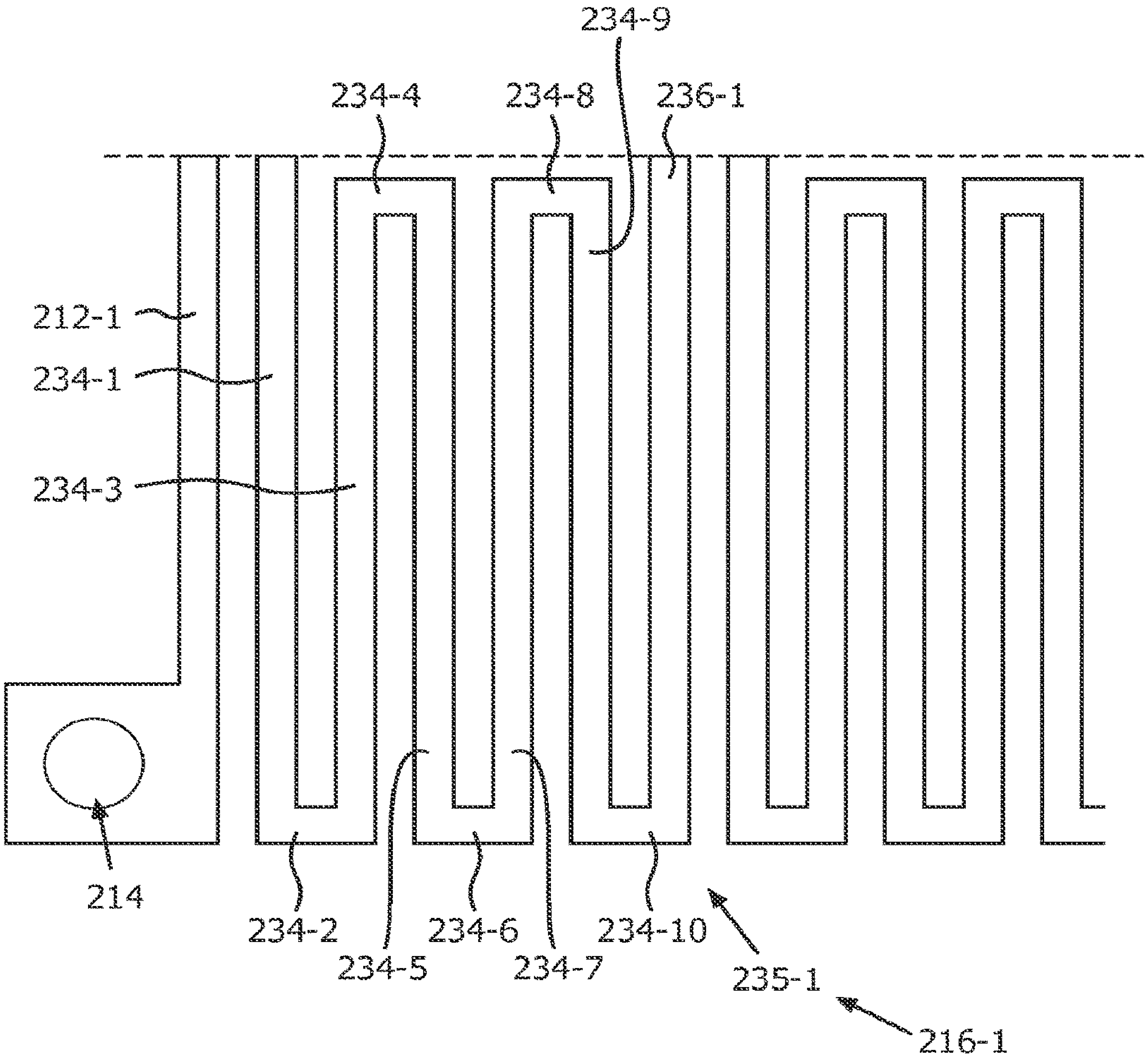
221-10
221-7
221-9

FIG. 2B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234-8
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234-1
234-3
214
234-2
234-6
234-10
234-5
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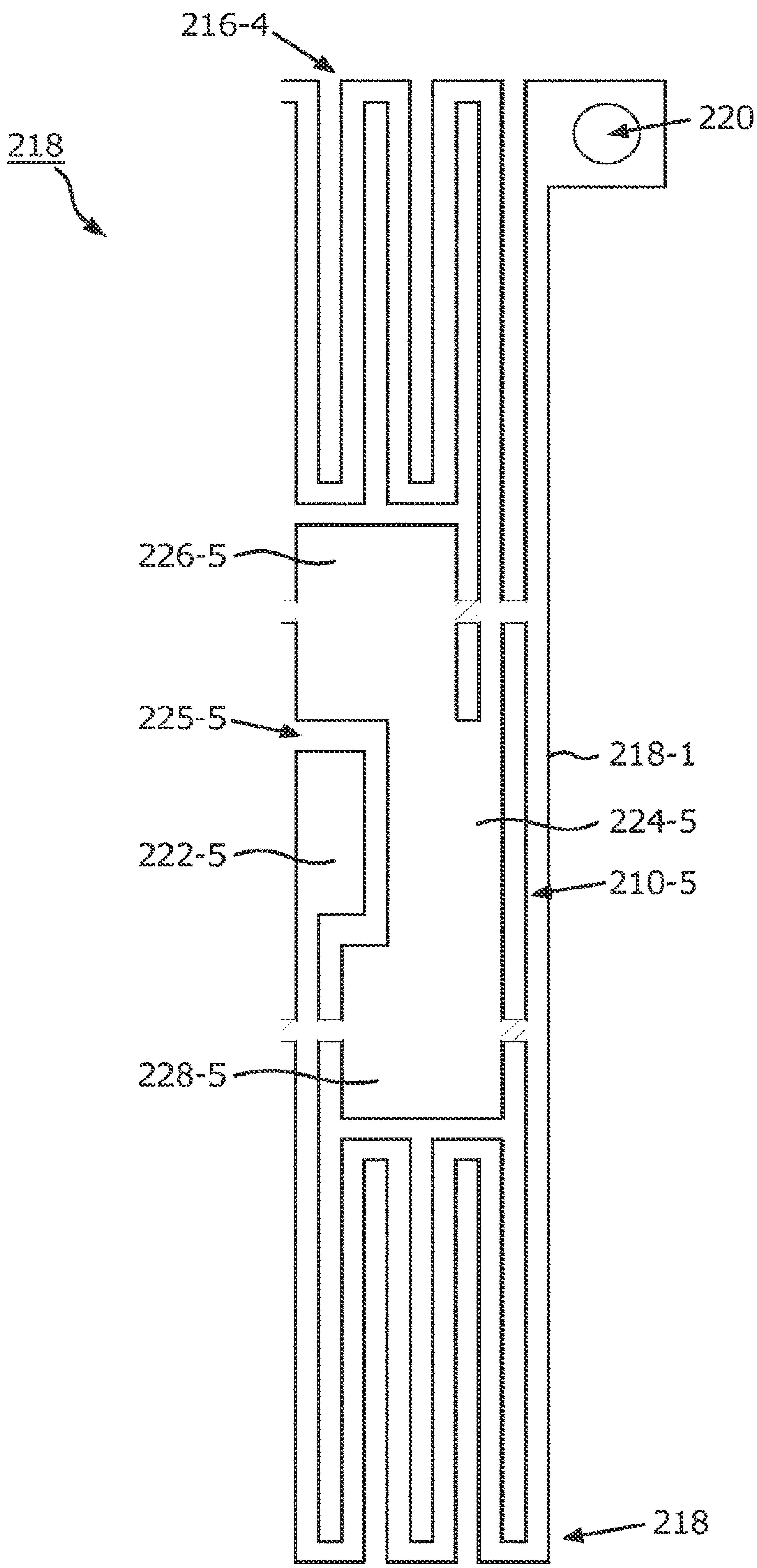
235-1
216-1

FIG. 2C



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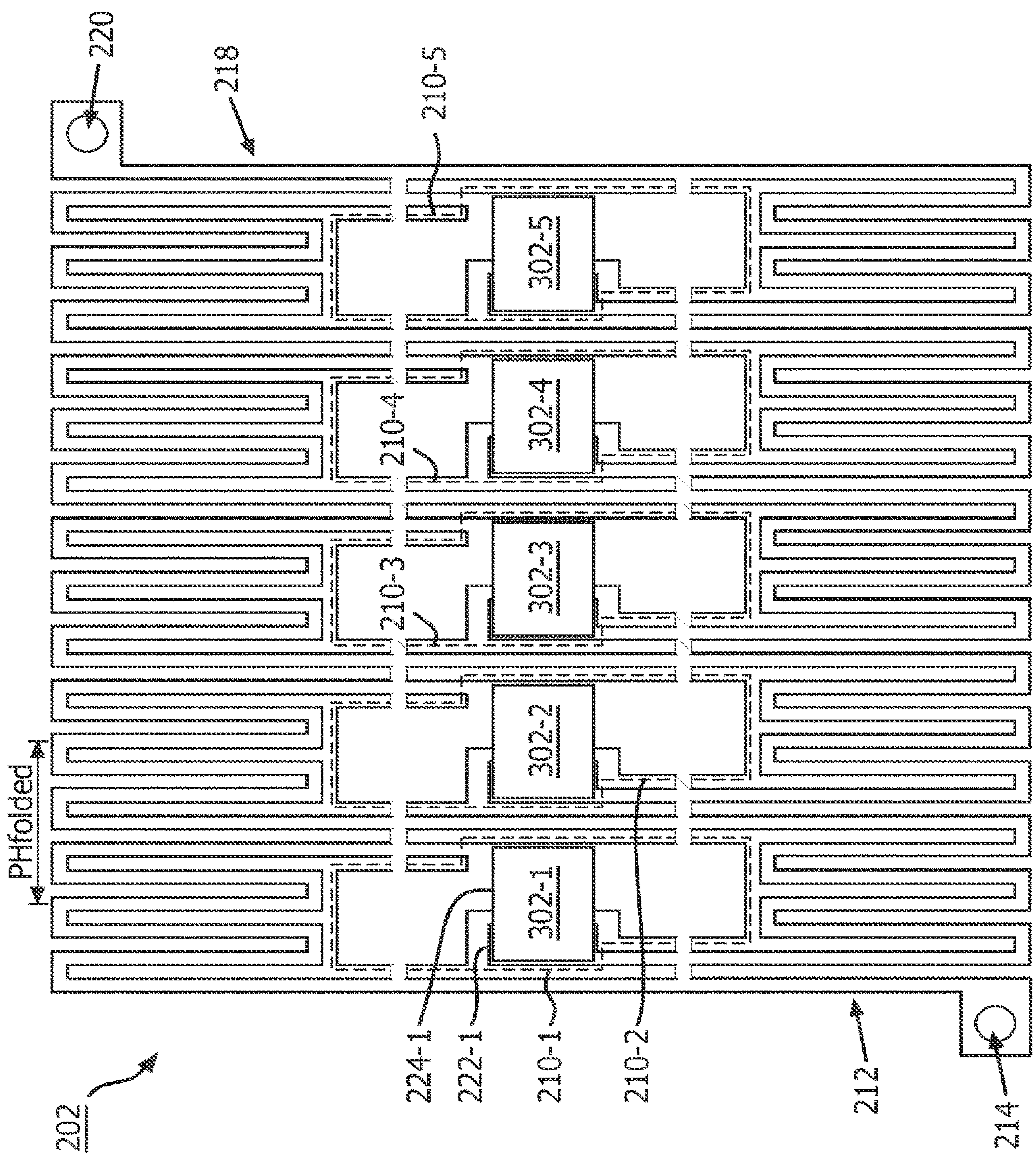
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302-5
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210-4
210-5
216-1
216-2
216-3
216-4
222-1
224-1

FIG. 3

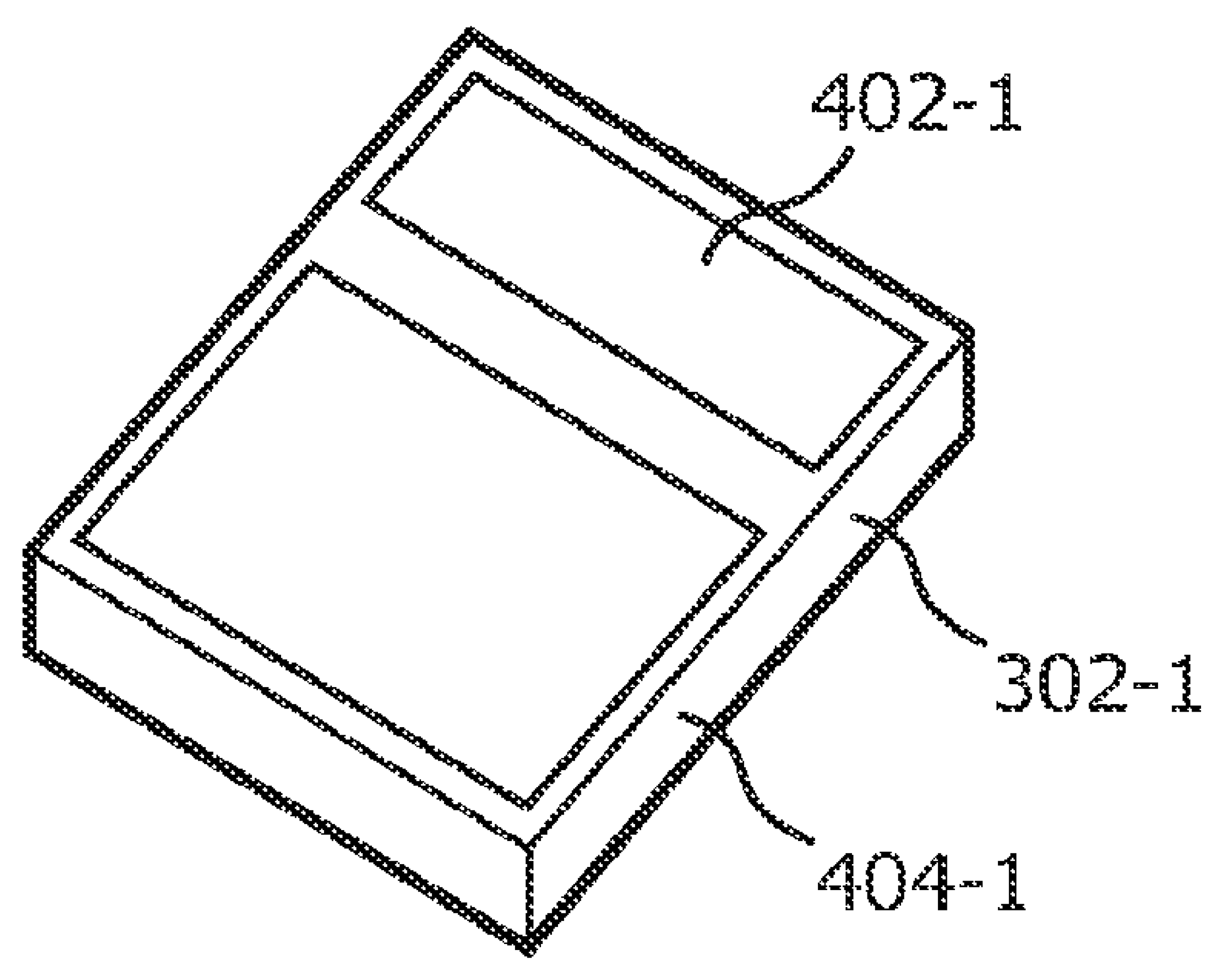
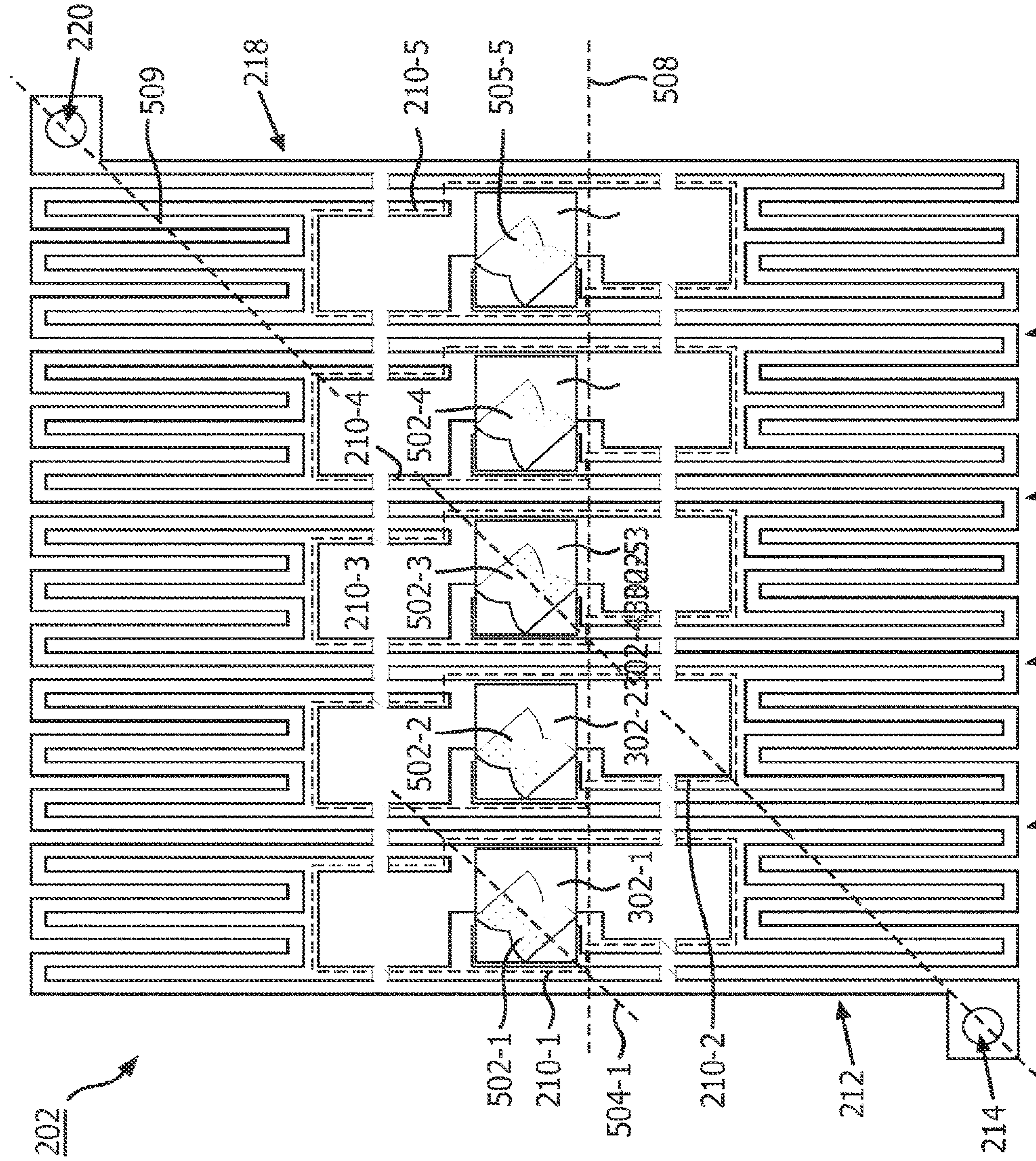


FIG. 4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504-1
210-2
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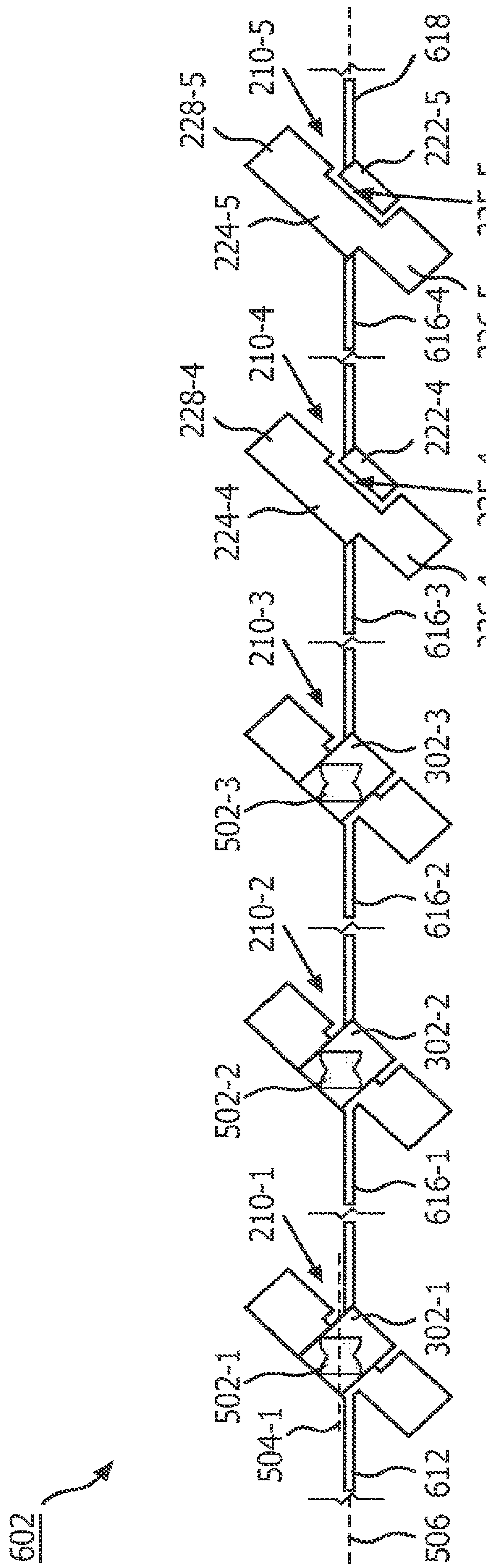
214

FIG. 5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210-3
616-3
224-4
228-4
226-4
225-4
222-4
210-4
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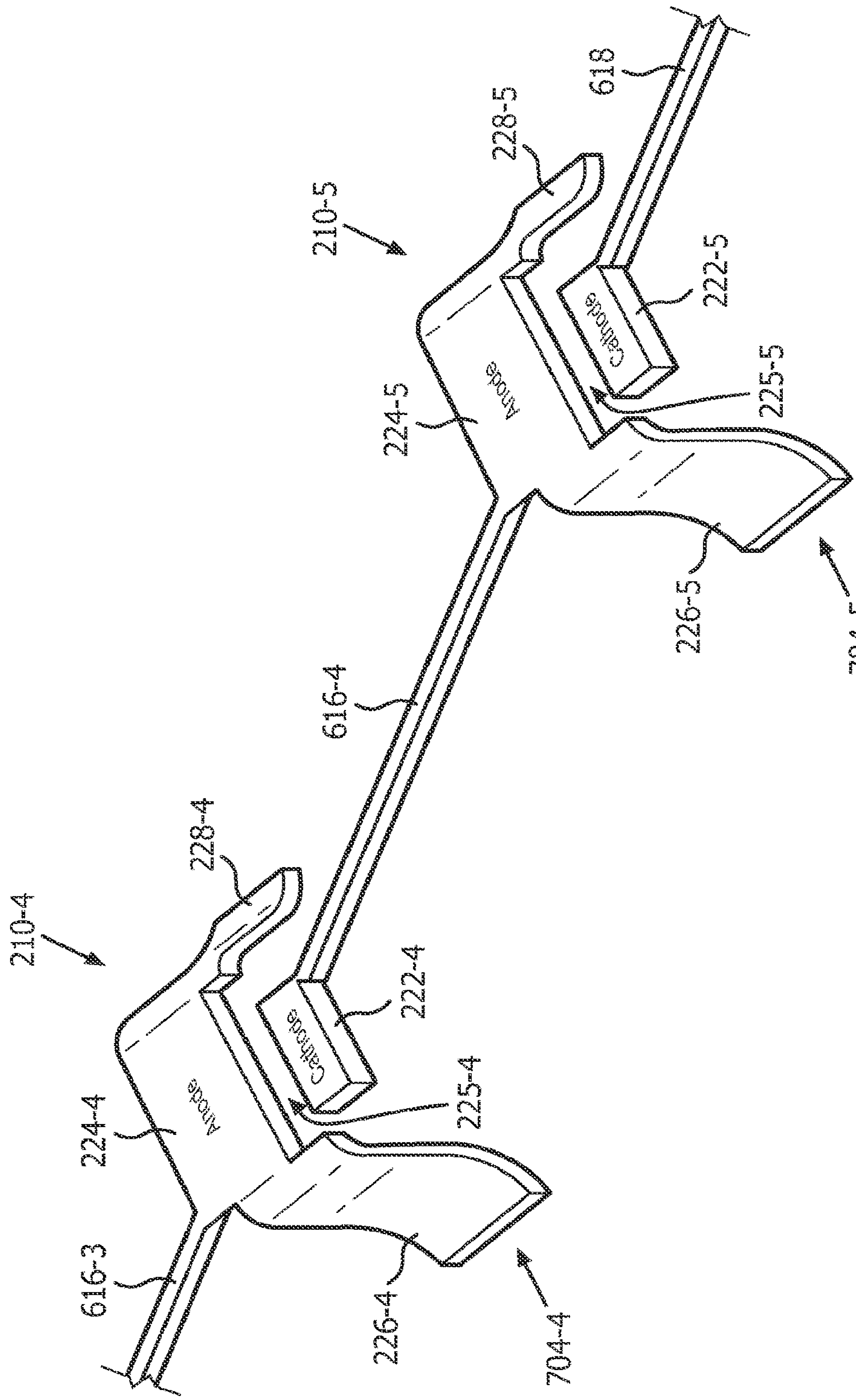
224-5
228-5
226-5
225-5
222-5
210-5
618

FIG. 6A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618
222-5
Cathode
Anode
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225-5
226-5
704-5
616-4
210-4
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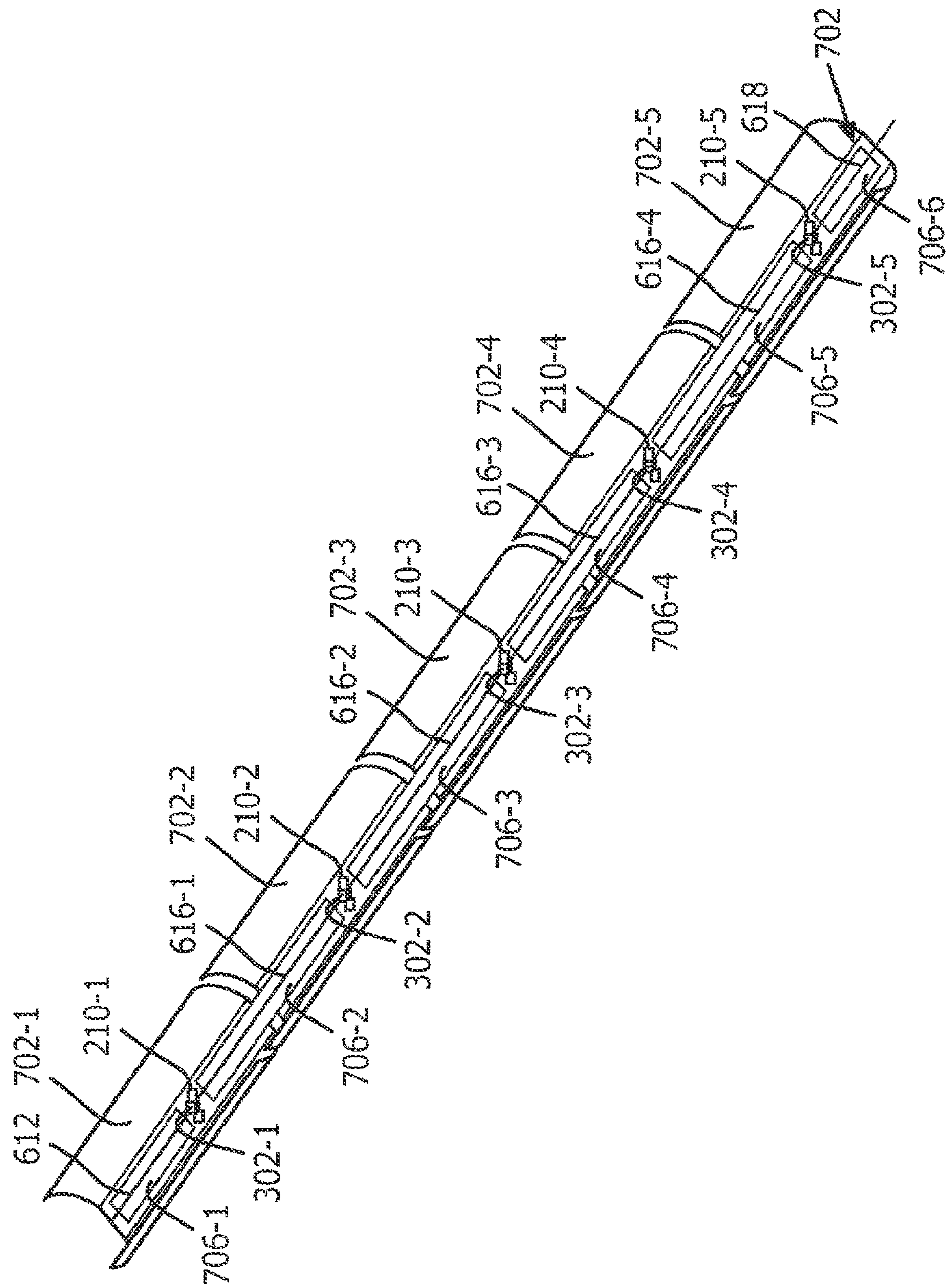
222-4
Cathode
Anode
224-4
225-4
616-3
226-4
704-4

FIG. 6B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618
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210-5
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706-6
302-5
706-5
702-4
210-4
616-3
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702-3
210-3
616-2
302-3
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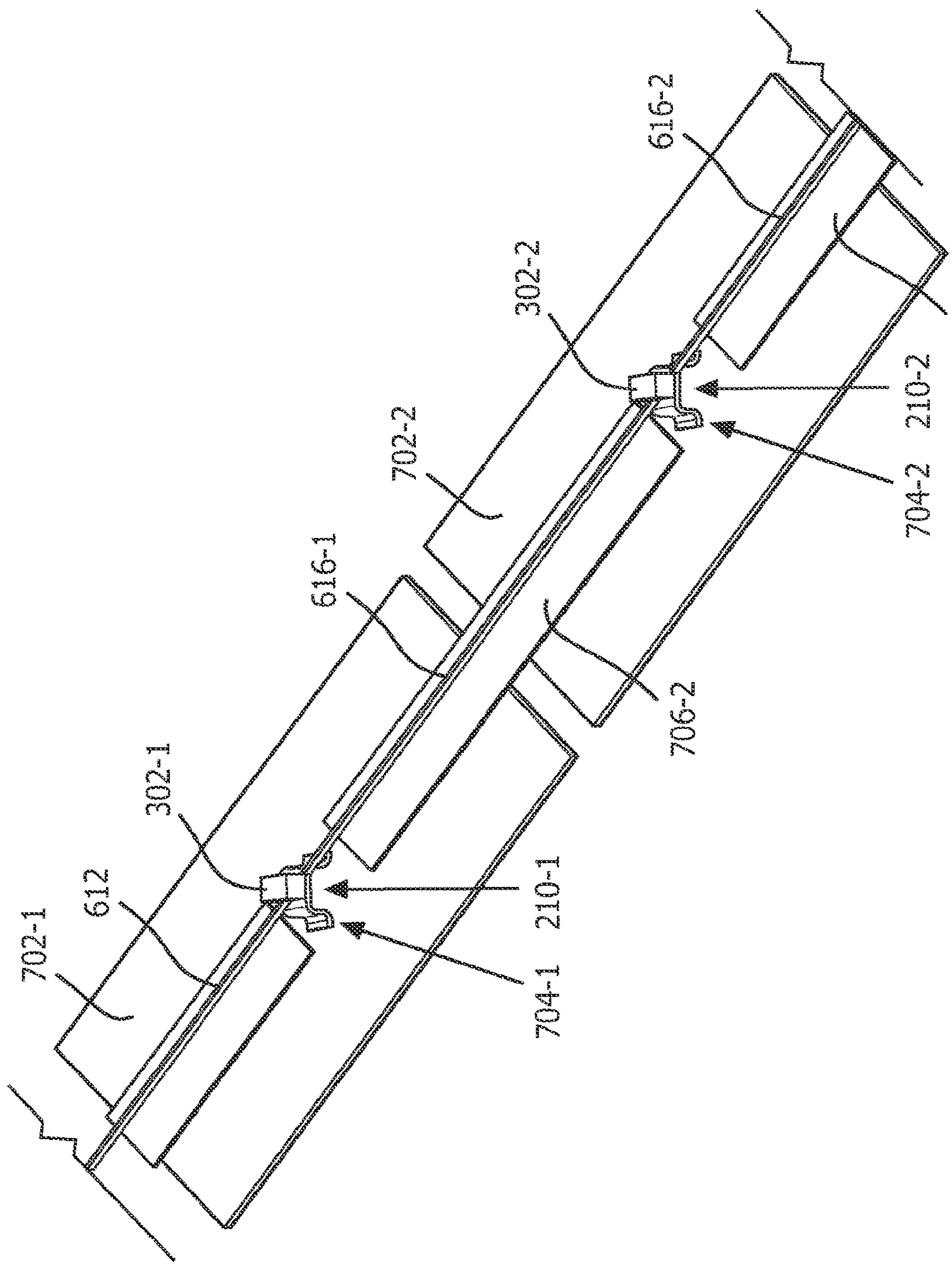
616-1
302-2
706-2
702-1
210-1
612
302-1
706-1

FIG. 7A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302-2
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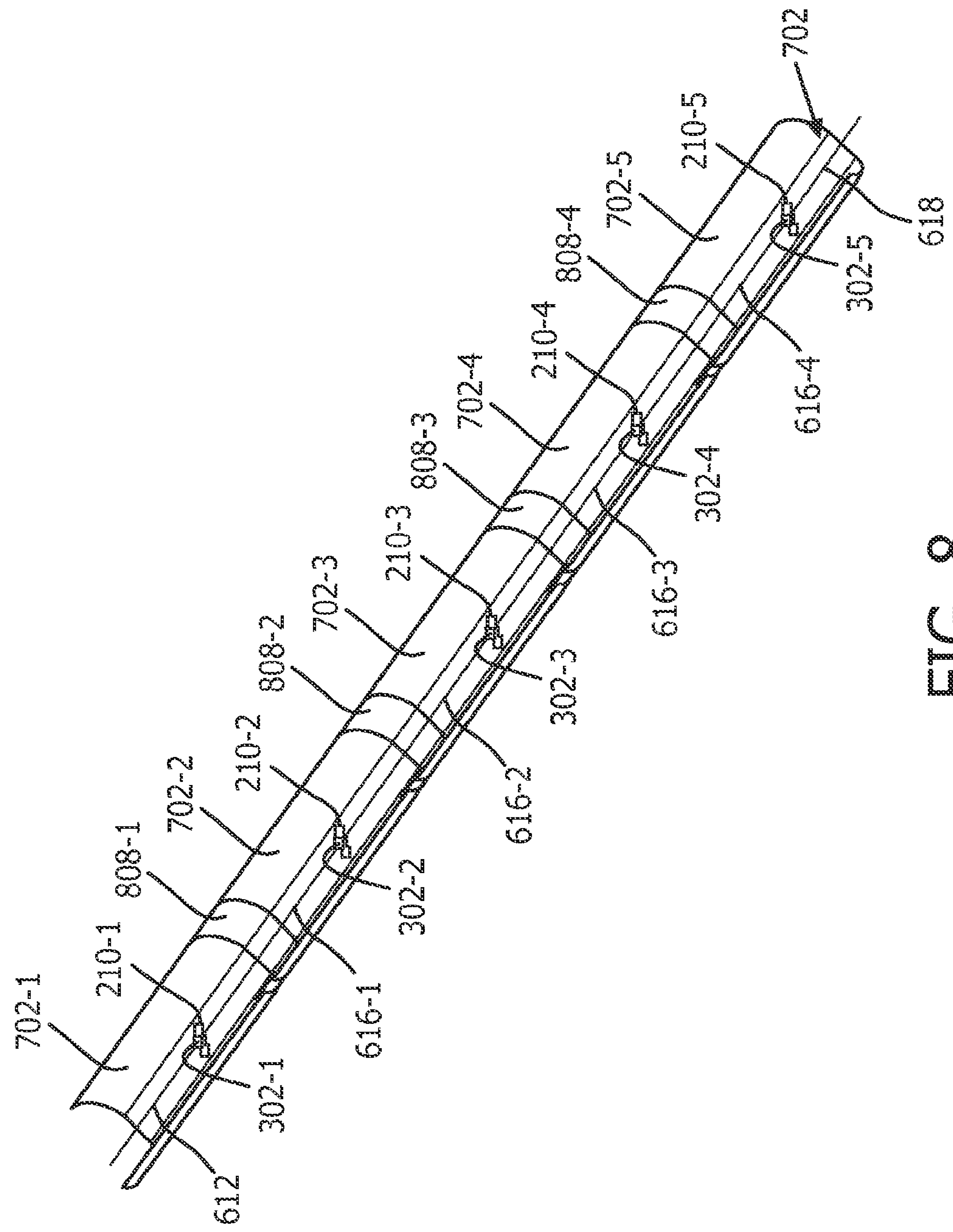
210-2
704-2
616-1
706-2
302-1
612
702-1
210-1
704-1

FIG. 7B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702-5
618
808-4
302-5
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808-3
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210-3
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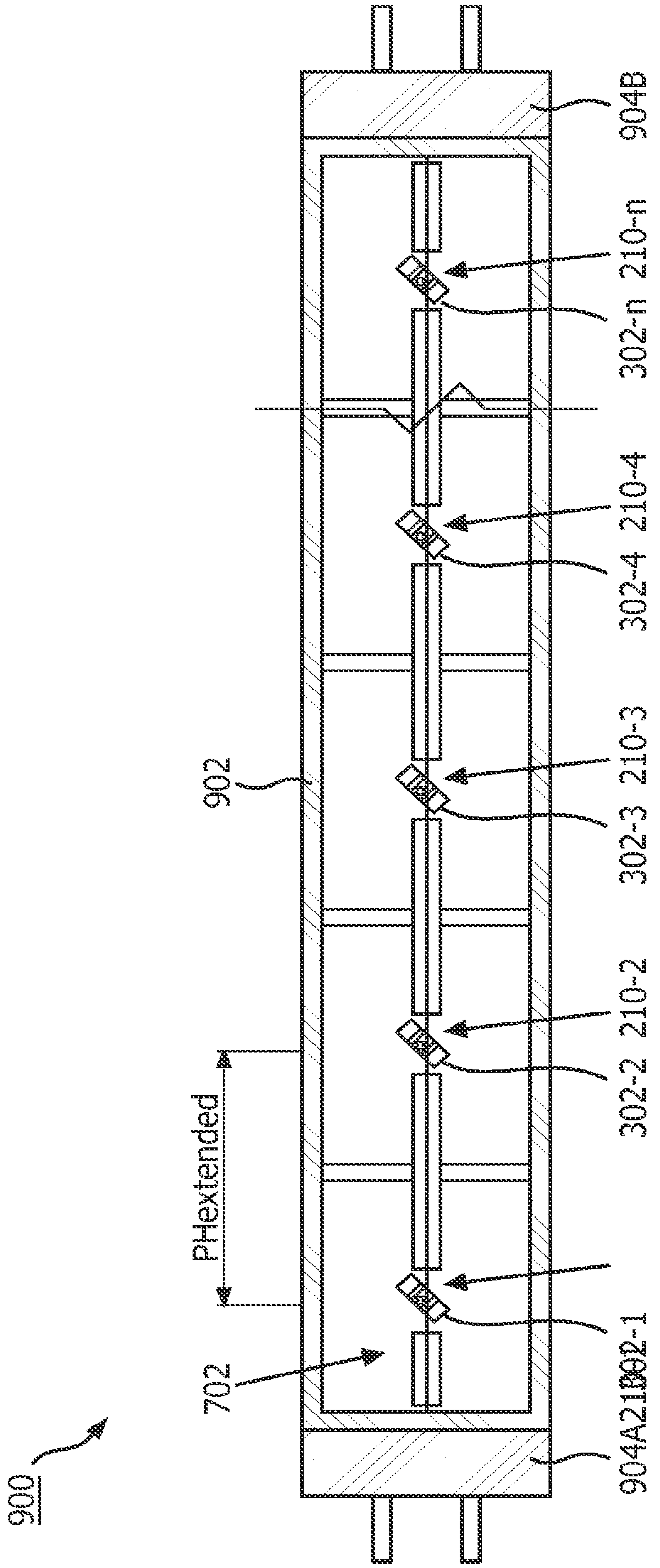
702-3
808-2
302-3
210-2
616-2
702-2
808-1
302-2
210-1
616-1
702-1
302-1
612

FIG. 8


904B
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302-n
210-4
302-4
902
210-3
302-3
210-2
302-2
PHextended
702
904A
302-1
900

FIG. 9

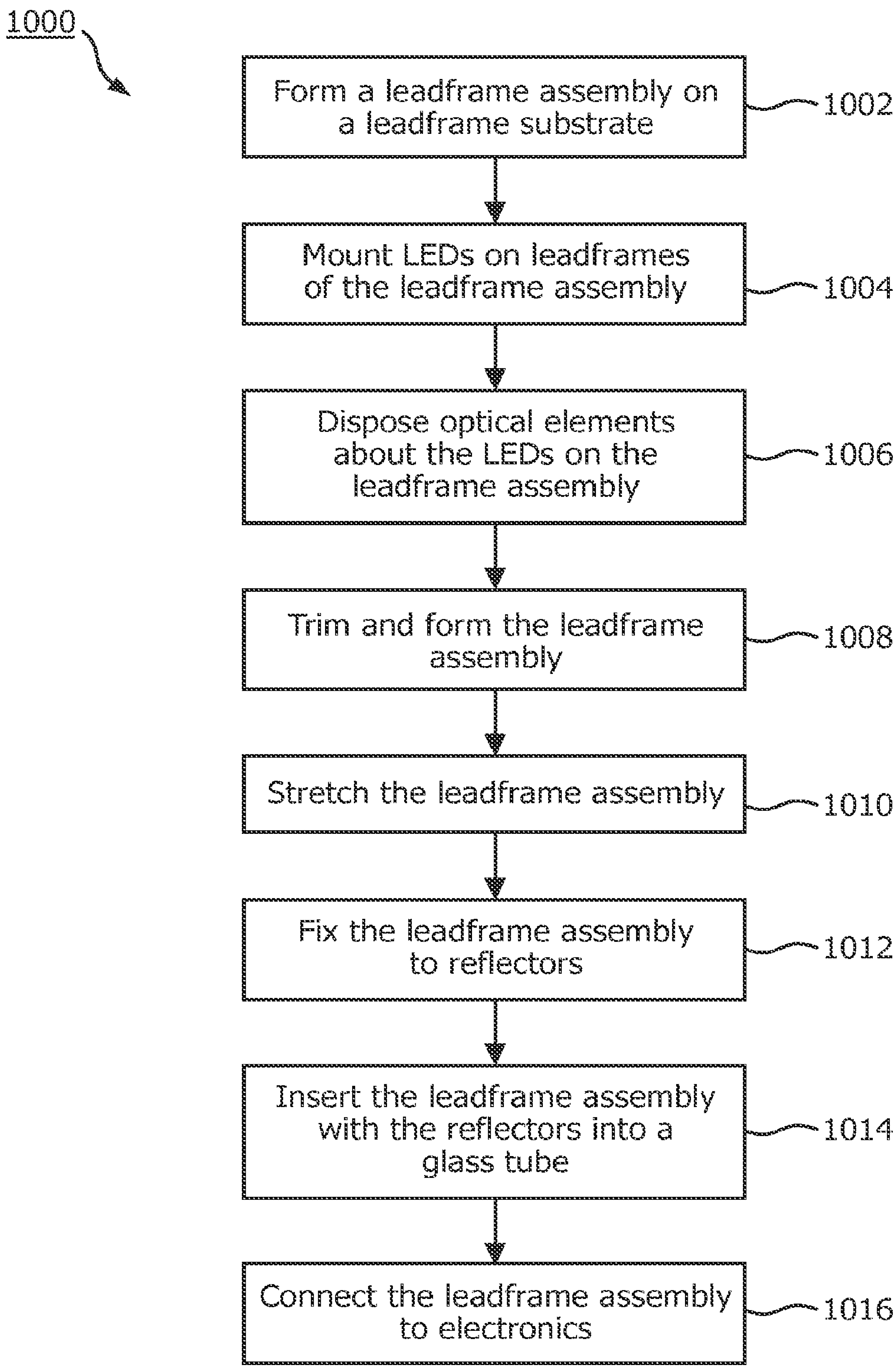
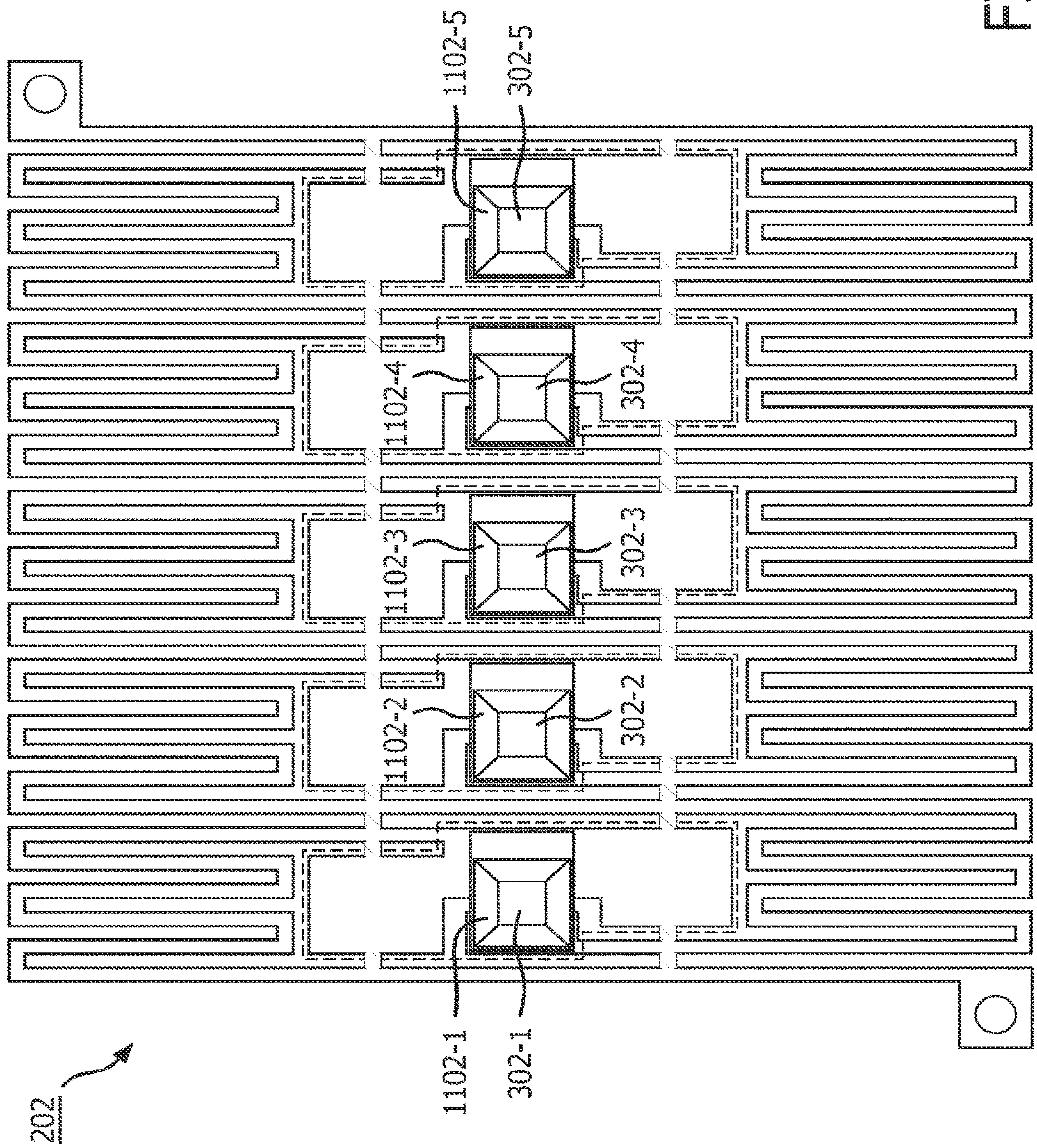
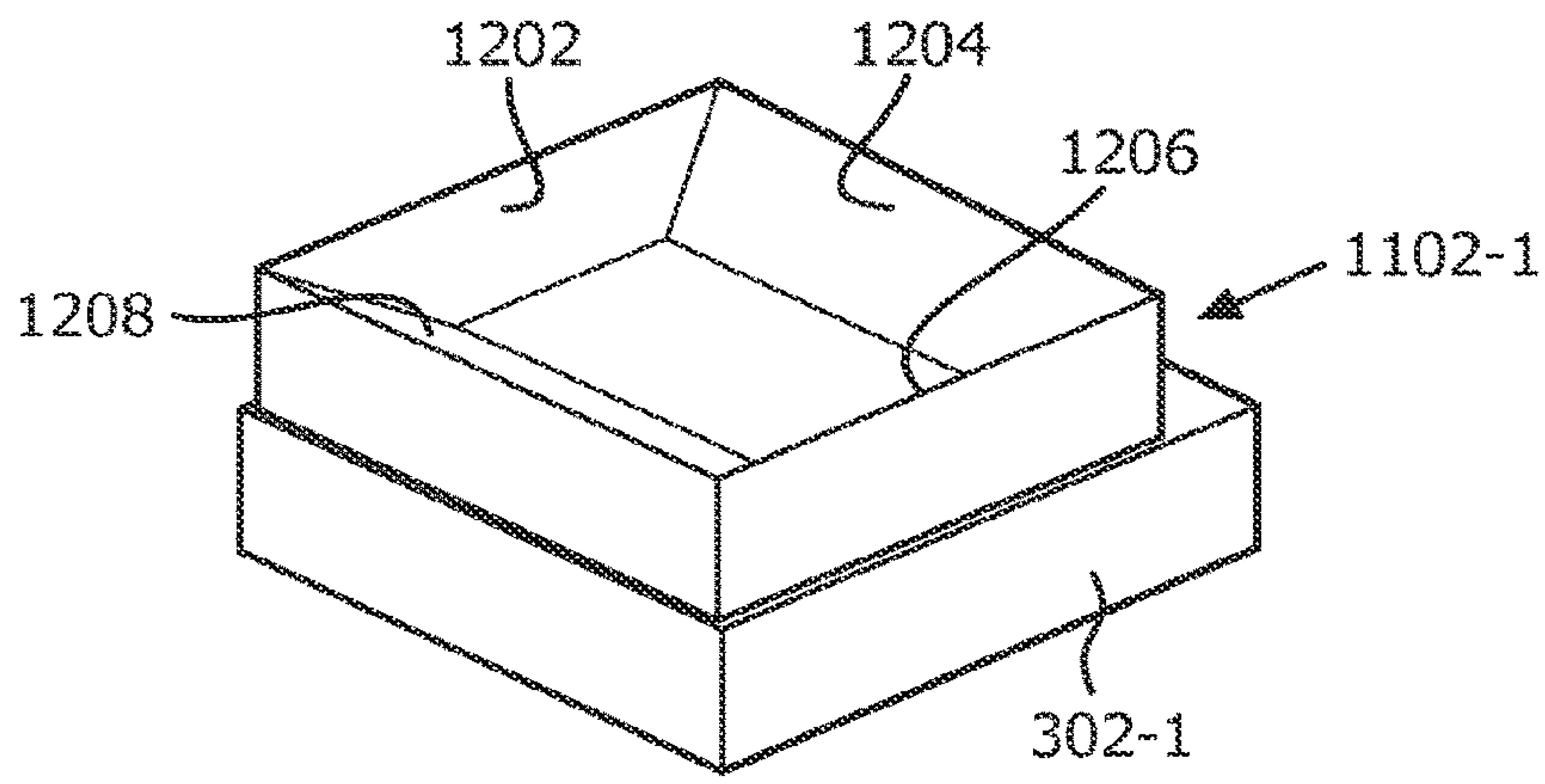

1000
Form a leadframe assembly on a leadframe substrate
1002
Mount LEDs on leadframes of the leadframe assembly
1004
Dispose optical elements about the LEDs on the leadframe assembly
1006
Trim and form the leadframe assembly
1008
Stretch the leadframe assembly
1010
Fix the leadframe assembly to reflectors
1012
Insert the leadframe assembly with the reflectors into a glass tube
1014
Connect the leadframe assembly to electronics
1016

FIG. 10

FIG. 11

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1206
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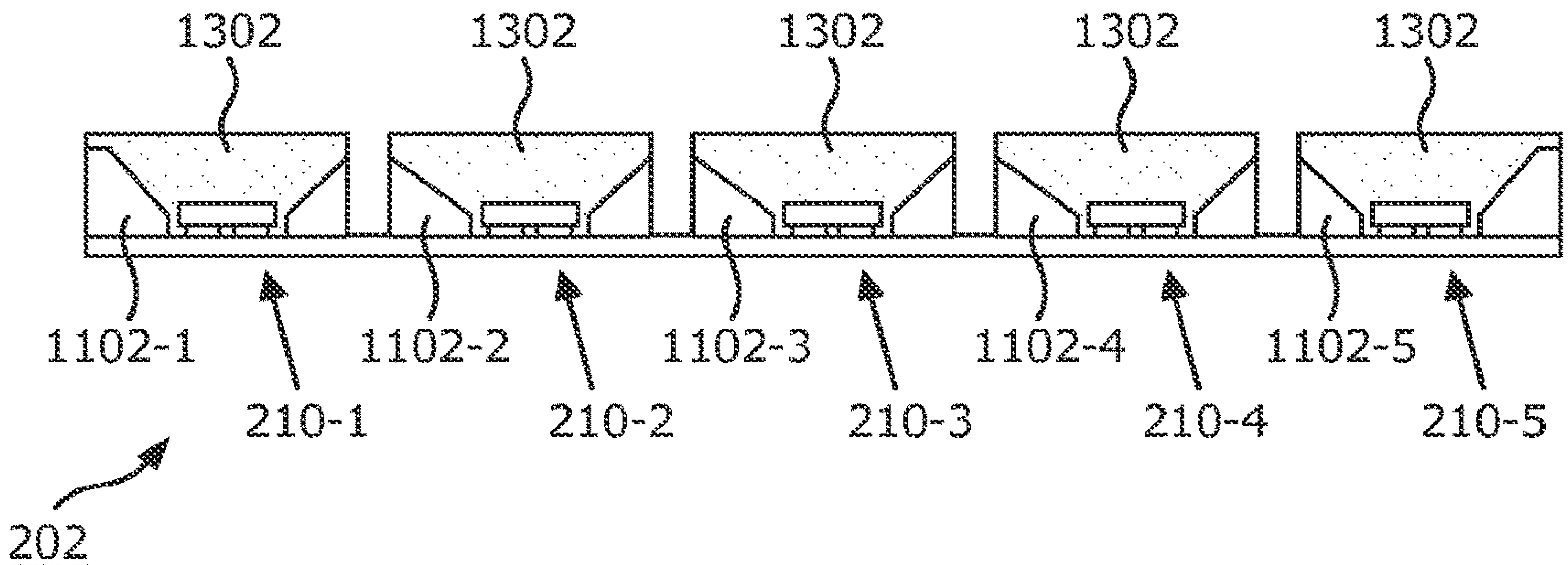
1102-1
302-1

FIG. 12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1302
1302
1302
1302
1102-1
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1102-3
210-3
1102-4
210-4
1102-5
210-5
202

FIG. 13

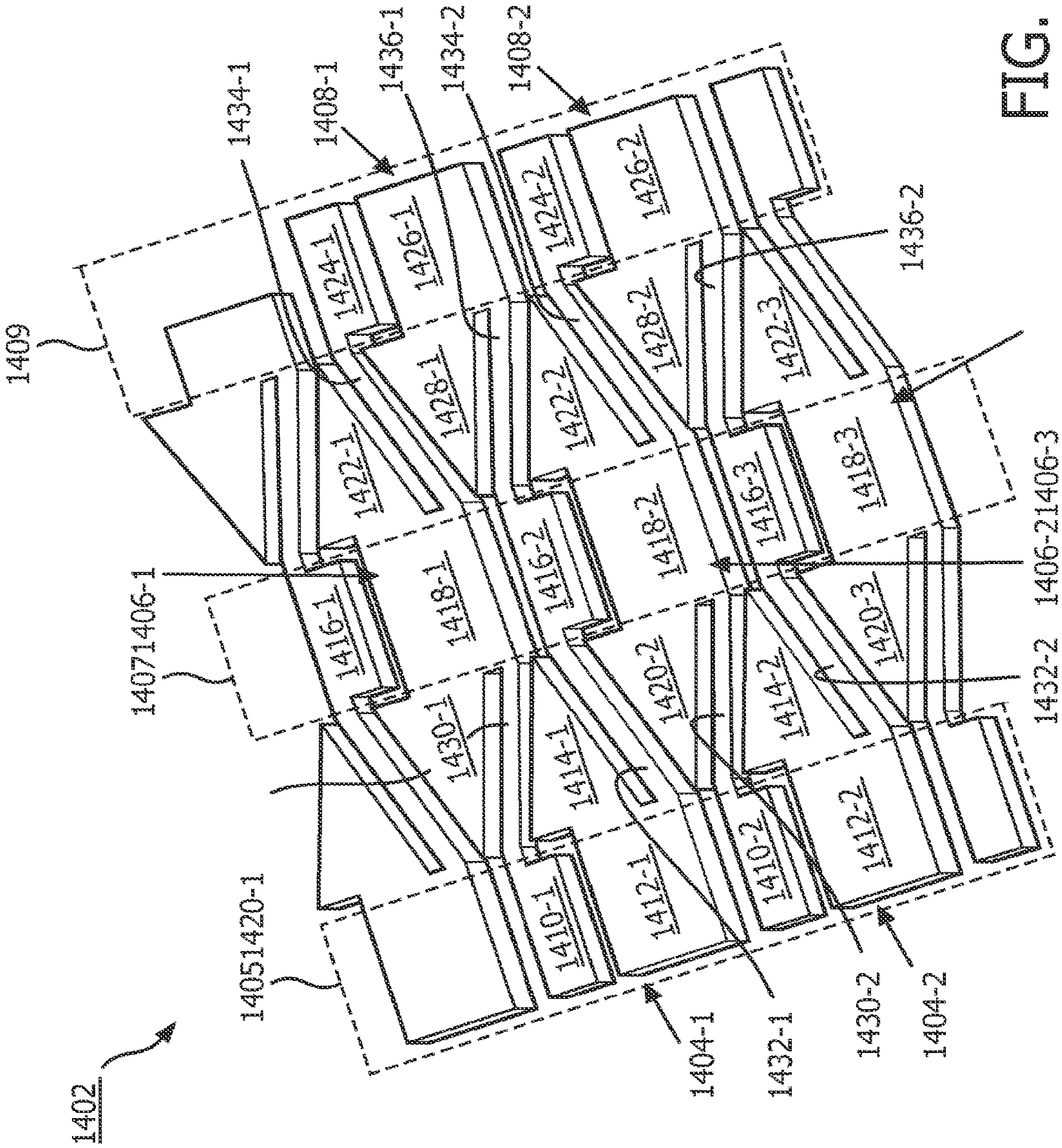
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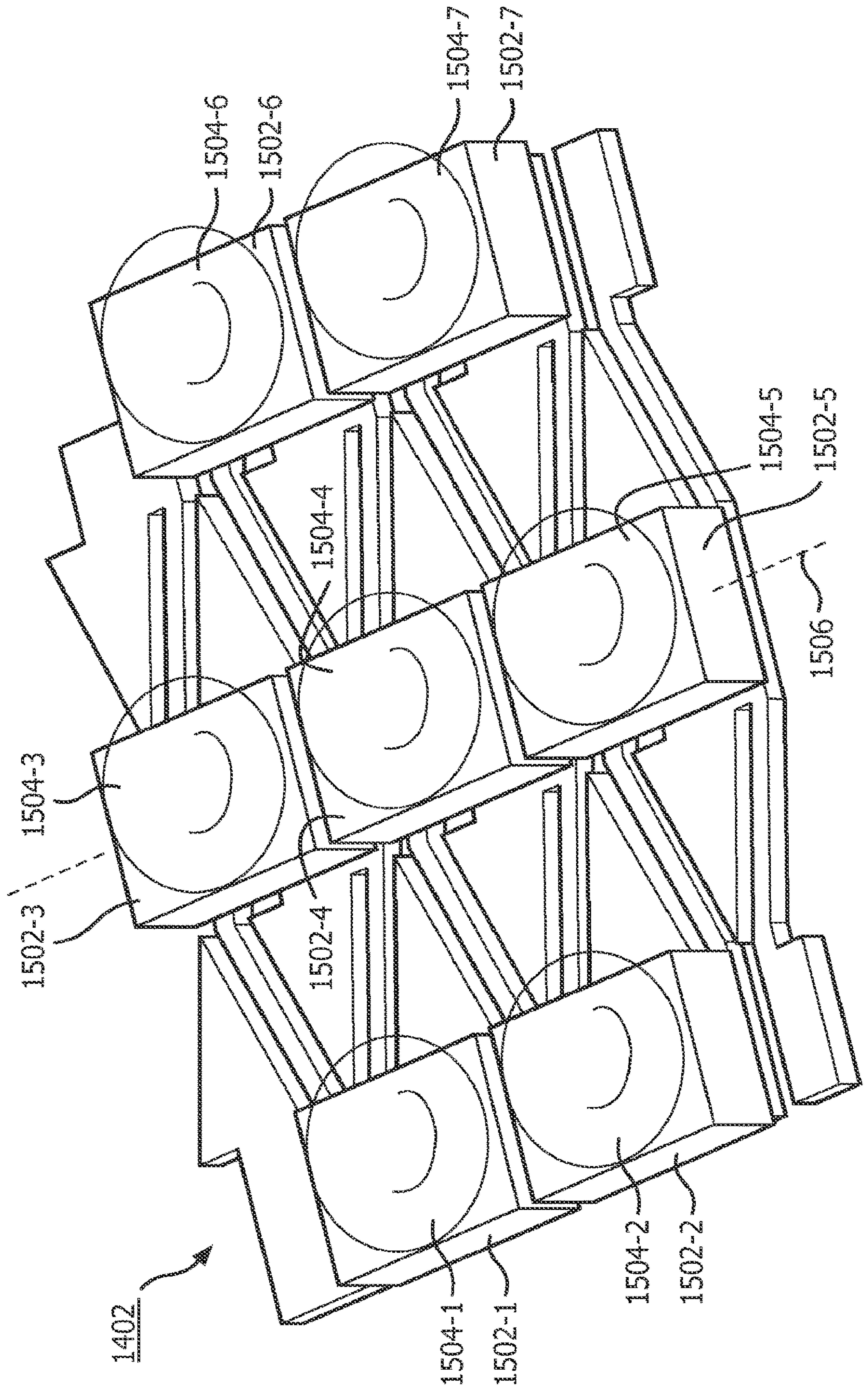
FIG. 14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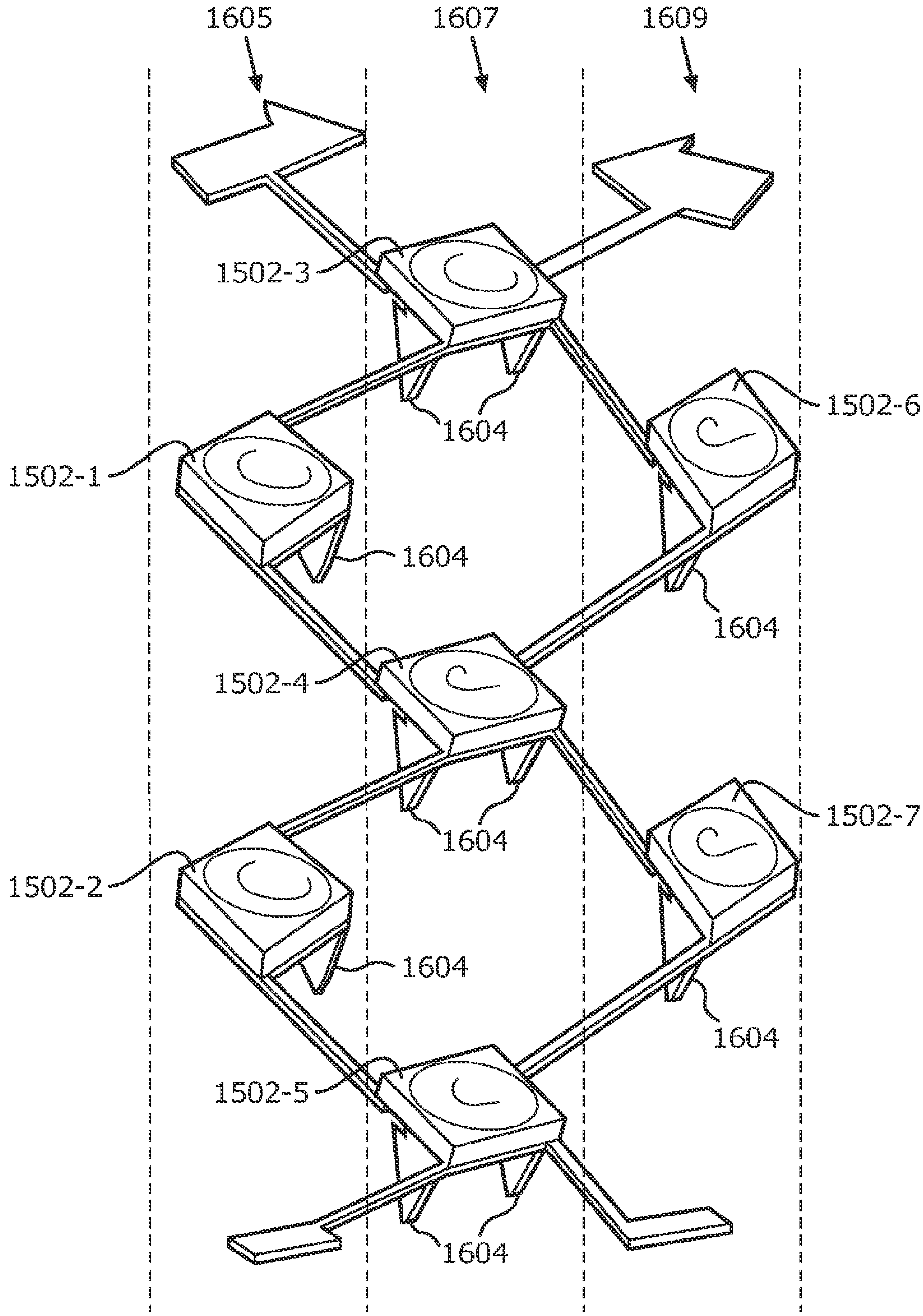
1502-2

FIG. 15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1609
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1502-2
1604
1604
1502-5
1604

FIG. 16

PRE-ROTATED OVERMOULDED BIDIRECTIONAL SPREADING LENS FOR STRETCHED LEADFRAME ARCHITECTURE

FIELD OF THE INVENTION

The present invention relates to architecture for linear lighting applications with large pitches or spaces between solid state light-emitting devices (LEDs), such as LED retrofit tube lamps for replacing fluorescent tube lamps.

BACKGROUND

Light-emitting device (LED) lamps are replacing florescent lamps in many lighting applications. LED lamps offer longer life, greater energy efficiency, and flicker-free lighting. LED lamps also do not contain mercury and do not interfere with precision instruments.

Fluorescent tube lamps are commonly used to provide ambient lighting in large indoor areas. These tube lamps are typically 2 to 8-feet long. For an equivalent LED retrofit tube lamp, a dense array of LEDs is mounted on a long printed circuit board (PCB). Both the number of the LEDs and the length of the PCB add to the cost of the LED tube lamp. Thus, what is needed is a new architecture for linear lighting applications with large pitches or spaces between LEDs.

SUMMARY

A method for manufacturing a solid state light-emitting device (LED) lighting apparatus includes forming a leadframe assembly which is a group of leadframes connected in series by folded interconnects. LEDs are then mounted on the leadframes, along with disposing optical elements about the LEDs. The leadframe assembly is then stretched so the interconnects unfold to distribute the LEDs spatially. Disposing (positioning) the optical elements about the LEDs includes orienting the optical elements so the optical elements provide a predetermined light pattern after stretching the leadframe assembly.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. **1** is a top cutaway view of a conventional light-emitting diode tube lamp with an array of light-emitting diodes mounted on a printed circuit board;

FIG. **2**A is a top view of a leadframe assembly;

FIGS. **2**B and **2**C combine to form a top view of the first and the second leadframes in the leadframe assembly of FIG. **2**A;

FIG. **2**D is a top view of the last leadframe in the leadframe assembly of FIG. **2**A;

FIG. **3** is a top view of light sources attached to the leadframes in the leadframe assembly of FIG. **2**A;

FIG. **4** is an isometric view of a light-emitting device (LED);

FIG. **5** is a top view of one type of optical elements disposed about the LEDs on the leadframe assembly of FIG. **3**;

FIG. **6**A is a top view of the stretched leadframe assembly of FIG. **5**;

FIG. **6**B is an isometric view of a portion of the stretched leadframe assembly of FIG. **6**A;

FIG. **7**A is an isometric view of the stretched leadframe assembly of FIG. **6**A fixed relative to reflectors with one configuration of insulating strips between the reflectors;

FIG. **7**B is an isometric view of two sections of the stretched leadframe assembly and the reflectors of FIG. **7**A;

FIG. **8** is an isometric view of the stretched leadframe assembly of FIG. **6**A fixed relative to the reflectors with a different configuration of insulating strips between the reflectors;

FIG. **9** is a top cutaway view of a tube lamp with the stretched leadframe assembly and the reflectors of FIG. **7**A;

FIG. **10** is a flowchart of a method for manufacturing the tube lamp of FIG. **9**;

FIG. **11** is a top view of a different type of optical elements disposed about the LEDs on the leadframe assembly of FIG. **3**;

FIG. **12** is an isometric view of a reflector cup mounted on an LED;

FIG. **13** is a side cross-sectional view of the optical elements disposed about the LEDs on the leadframe assembly of FIG. **11**;

FIG. **14** is an isometric view of a leadframe assembly with three rows of leadframes;

FIG. **15** is an isometric view of LEDs and optical elements on the leadframe assembly of FIG. **14**; and

FIG. **16** is an isometric view of the leadframe assembly of FIG. **15** after stretching, all arranged in accordance with embodiments of the invention.

Use of the same reference numbers in different figures indicates similar or identical elements.

DETAILED DESCRIPTION

FIG. **1** is a top cutaway view of a conventional solid state light-emitting diode tube lamp **100**. Tube lamp **100** has the form factor of a standard straight fluorescent tube lamp, such as a T5, T8, or T12 fluorescent tube lamp or any other suitable lamp. Tube lamp **100** includes a glass tube **102** and bi-pin connectors **104**A, **104**B mounted on the two ends of the glass tube so the tube lamp can connect to standard fluorescent lighting fixtures. Although a standard fluorescent tube lamp is shown, any other dispersed use of LEDs is contemplated and included within the scope of the invention.

An array of light-emitting diodes **106** (only some are labeled) is mounted on a large printed circuit board (PCB) **108** that runs along the length of glass tube **102**. The array typically consists of three staggered rows of light-emitting diodes **106**, but any suitable arrangement for dispersing light is contemplated and included within the scope of the invention. To avoid a spotty appearance, the horizontal pitch Ph and the vertical pitch Pv between light-emitting diodes **106** are controlled to provide the appearance of a single, uniformly lit light source. With typical pitches Ph and Pv of about 0.5 inch, about 300 light-emitting diodes are required for a typical 4-foot long tube lamp **100**. Alternate rows may be offset, for instance alternate rows may be displaced at half the pitch Ph.

PCB **108** connects light-emitting diodes **106**, in series or in parallel or a combination of serial strings of LEDs driven in parallel, to an external power source. PCB **108** has an area roughly equal to the product of the diameter and the length of glass tube **102**. Although relatively simple in construction, PCB **108** has a very large area compared to many LED applications. The large number of light-emitting diodes **106** and the large area of PCB **108** all add to the cost of tube lamp **100**.

A stretchable leadframe assembly may be used in place of PCB **108**. The leadframe assembly includes leadframes that are connected in series, both mechanically and electrically, by folded interconnects. Each leadframe includes an anode pad and a cathode pad. Once light sources are attached to the leadframes, the leadframe assembly is stretched to distribute the light sources spatially. The small area of the folded interconnects saves material and processing space compared to a conventional PCB.

FIG. **2**A illustrates a top view of a leadframe assembly **202** in one or more embodiments of the present invention. Leadframe assembly **202** is in a folded configuration typically used early in the manufacturing process. Later leadframe assembly **202** is stretched into a different configuration for placement in a light-emitting diode tube lamp. The following description uses an orientation of the leadframe segments where a stretch hole **214** is at the lower left corner of leadframe assembly **202**. The term segment refers to any typical straight member of leadframe assembly **202**.

Leadframe assembly **202** includes a group of leadframes **210-1**, **210-2**, **210-3**, **210-4**, and **210-5**. For example, leadframes **210-1** to **210-5** are linearly arranged in a row going from left to right. Each leadframe includes a rectangular cathode pad and a larger anode pad cut out to partially surround the cathode pad. Starting from the left side of FIG. **2**A, a folded interconnect **212** has a stretch hole **214** at a leftmost end and a rightmost end connected to the anode pad of leadframe **210-1**. Folded interconnect **212** includes a vertical segment typically located to the left of leadframe **210-1** and a folded section of segments typically located at the top of leadframe **210-1**.

Each pair of adjacent leadframes are connected by a folded interconnect. Leadframes **210-1** is connected by a folded interconnect **216-1** to leadframe **210-2**. Folded interconnect **216-1** includes a leftmost end connected to the cathode pad of leadframe **210-1** and a rightmost end connected to the anode pad of leadframe **210-2**. Folded interconnect **216-1** includes a first folded section of segments typically located at the bottom of leadframe **210-1**, a vertical segment typically located between leadframes **210-1** and **210-2**, and a second folded section of segments typically located at the top of leadframe **210-2**.

Leadframe **210-2** is connected by a folded interconnect **216-2** to leadframe **210-3**, which is connected by a folded interconnect **216-3** to leadframe **210-4**, which is connected by a folded interconnect **216-4** to leadframe **210-5**. Folded interconnects **216-2**, **216-3**, and **216-4** are configured similarly to folded interconnect **216-1**.

Folded interconnect **218** has a leftmost end connected to the cathode pad of leadframe **210-5** and a stretch hole **220** at a rightmost end. Folded interconnect **218** includes a folded section of segments typically located at the bottom of leadframe **210-5** and a vertical segment typically located to the right of leadframe **210-5**. Depending on the specific application, leadframe assembly **202** may include a greater or lesser number of leadframes and folded interconnect elements (e.g., leadframes **210-1** to **210-*n*** where n is a variable).

FIGS. **2**B and **2**C combine to illustrate a top view of leadframes **210-1** and **210-2** in one or more embodiments of the present invention. Leadframe **210-1** includes a cathode pad **222-1** and an anode pad **224-1**. Cathode pad **222-1** may be rectangular and anode pad **224-1** may be generally rectangular with a cutout **225-1** that fits around the cathode pad. Anode pad **224-1** includes an upper wing area **226-1** above cutout **225-1** and a lower wing area **228-1** below cutout **225-1**. Wing areas **226-1** and **228-1** are later bent to form a gull wing mount. Like leadframe **210-1**, leadframe **210-2** includes a cathode pad **222-2** and an anode pad **224-2** with a cutout **225-2** and wing areas **226-2**, **228-2**. Leadframes **210-3** to **210-5** (FIG. **2**A) are configured similarly to leadframes **210-1** and **210-2**.

As described above, a folded interconnect **212** is connected to leadframe **210-1**. Folded interconnect **212** includes a vertical segment **212-1** typically located to the left of leadframe **210-1**. Vertical segment **212-1** has stretch hole **214** at one end and another end connected to a top folded section **232-1**.

Top folded section **232-1** is shaped like a rectangular waveform, has one end connected to vertical segment **212-1**, and another end connected to anode pad **224-1** of leadframe **210-1**. Top folded section **232-1** includes a horizontal segment **212-2** extending rightward from segment **212-1** to connect to a vertical segment **212-3** which extends downward to connect to a horizontal segment **212-4**. Horizontal segment **212-4** extends rightward to connect to a vertical segment **212-5**, which extends upward to connect to a horizontal segment **212-6**. Horizontal segment **212-6** extends rightward to connect to a vertical segment **212-7**, which extends downward to connect to a horizontal segment **212-8**. Horizontal segment **212-8** extends rightward to connect to a vertical segment **212-9**, which extends upward to connect to a horizontal segment **212-10**. Horizontal segment **212-10** extends rightward to connect to a vertical segment **212-11**, which extends downward to connect to anode pad **224-1** of leadframe **210-1**. In the alternative, the top folded section of folded interconnect **212** may have the shape of a sinusoidal waveform, saw tooth waveform or any other suitable shape.

As described above, leadframe **210-1** is connected by folded interconnect **216-1** to leadframe **210-2**. Folded interconnect **216-1** includes a bottom folded section **235-1** typically located at the bottom of leadframe **210-1**, a vertical segment **236-1** typically located between leadframes **210-1** and **210-2**, and a top folded section **239-1** typically located at the top of leadframe **210-2**. Bottom folded section **235-1** is shaped like a rectangular waveform, has one end connected to cathode pad **222-1** of leadframe **210-1**, and another end connected to vertical segment **236-1**. Bottom folded section **235-1** has a vertical segment **234-1** extending downward to connect to a horizontal segment **234-2**, which extends rightward to connect to a vertical segment **234-3**. Vertical segment **234-3** extends upward to connect to a horizontal segment **234-4**, which extends rightward to connect to a vertical segment **234-5**. Vertical segment **234-5** extends downward to connect to a horizontal segment **234-6**, which extends rightward to connect to a vertical segment **234-7**. Vertical segment **234-7** extends upward to connect to a horizontal segment **234-8**, which extends rightward to connect to a vertical segment **234-9**. Vertical segment **234-9** extends downward to connect to a horizontal segment **234-10**, which extends rightward to connect to vertical segment **236-1**. In the alternative, folded section **235-1** may have the shape of a sinusoidal waveform, sawtooth waveform or any other suitable shape.

Vertical segment **236-1** passes between leadframes **210-1** and **210-2**. Vertical segment **236-1** has a lower end connected to bottom folded section **235-1** and an upper end connected to top folded section **239-1**.

Top folded section **239-1** is shaped like a rectangular waveform, has one end connected to vertical segment **236-1**, and another end connected to anode pad **224-2** of leadframe **210-2**. Top folded section **239-1** is configured similarly to top folded section **232-1** of folded interconnect **212**.

Leadframe assembly **202** includes sacrificial ties, which are collectively referred to as sacrificial ties **221**, that connect portions of a folded interconnect to other portions of same or different folded interconnect or to an anode or cathode pad. Sacrificial ties **221** add stiffness to leadframe assembly **202** so that it is sufficiently rigid for handling during the manufacturing process. Sacrificial ties **221** are later removed so the folded interconnects **212**, **216-1** to **216-4**, and **218** (FIG. 2A) may unfold to distribute leadframes **210-1** to **210-5**.

In FIG. 2B, sacrificial ties **221** are shown as crosshatched areas even though they are typically created by the same process as is used to create all of folded interconnects **212**, **216-1** to **216-4**, and **218**. The crosshatching is used only to distinguish sacrificial ties **221** in the figures from the portions of leadframe assembly **202** that remain after processing.

In FIG. 2B, sacrificial tie **221-1** connects segment **212-1** to upper wing area **226-1**. Sacrificial tie **221-2** connects upper wing area **226-1** to segment **212-11**. Sacrificial tie **221-3** connects segment **212-11** to segment **236-1**. Sacrificial tie **221-4** connects segment **236-1** to upper wing area **226-2**. Sacrificial tie **221-5** connects upper wing area **226-2** to vertical segment **239-1**. Sacrificial tie **221-6** connects segment **212-1** to segment **234-1**. Sacrificial tie **221-7** connects segment **234-1**-to lower wing area **228-1**. Sacrificial tie **221-8** connects lower wing area **228-1** to segment **236-1**. Sacrificial tie **221-9** connects segment **236-1** to a segment **234-2**. Sacrificial tie **221-10** connects segment **234-2** to lower wing area **228-2**.

Folded interconnects **216-2**, **216-3**, and **216-4** (FIG. 2A) are configured similarly to folded interconnect **216-1**.

FIG. 2D illustrates a top view of leadframe **210-5** in one or more embodiments of the present invention. Leadframe **210-5** includes a cathode pad **222-5** and an anode pad **224-5** with a cutout **225-5** and wing areas **226-5**, **228-5**.

As described above, leadframe **210-5** is connected to folded interconnect **218** with stretch hole **220** at its end. Folded interconnect **218** includes a bottom folded section typically located at the bottom of leadframe **210-5** and a vertical segment **218-1** typically located to the right of leadframe **210-5**. Folded interconnect **218** is substantially folded interconnect **212** in the reverse configuration.

FIG. **3** shows light sources **302-1**, **302-2**, **302-3**, **302-4**, and **302-5** are soldered or otherwise electrically connected to leadframes **210-1** to **210-5**, respectively, in one or more embodiments of the present invention. When connected to leadframes **210-1** to **210-5**, LEDs **302-1** to **302-5** are spaced with a horizontal pitch of PHfolded. The attachment of a light source to a leadframe mechanically binds the cathode and the anode pads of the leadframe together even after sacrificial ties **221** (shown as hatched segments in FIGS. 2A and 2B) are removed. Light sources **302-1** to **302-5** may be solid state light-emitting devices (LEDs).

FIG. **4** shows that exemplary LED **302-1** has a cathode pad **402-1** and an anode pad **404-1** that corresponds to cathode pad **222-1** and anode pad **224-1**, respectively, of leadframe **210-1** (FIG. **3**) in one or more embodiments of the present invention. The cathode pad **402-1** and anode pad **404-1** may or may not be shaped to the same dimensions as cathode pad **222-1** and anode pad **224-1** of leadframe **210-1**. In an alternative, cathode pad **402-1** may be approximately the shape of the center of anode pad **224-1**. Referring back to FIG. **3**, the cathode and anode pads of LEDs **302-2** to **302-5** are configured similarly to the pads of LED **302-1**.

LEDs **302-1** to **302-5** may be naked light-emitting diode dice or prepackaged light-emitting diodes (e.g., in chip scale packages). A prepackaged light-emitting diode has a naked light-emitting diode die mounted on a submount or interposer. The submount includes a ceramic substrate, a metal interconnect layer, and various pads. The ceramic substrate provides mechanical support and thermally connects the light-emitting diode die to a thermal pad on the bottom of the ceramic substrate. The metal interconnect layer connects the light-emitting diode die to a cathode pad and an anode pad on the bottom of the ceramic substrate. The prepackaged light-emitting diode die may or may not be encapsulated.

Once leadframe assembly **202** is stretched, a sparse arrangement of LEDs **302-1** to **302-5** may result in a tube lamp with a spotty appearance where the LEDs produce bright spots separated by dark regions along the length of the tube lamp. FIG. **5** shows optical elements **502-1**, **502-2**, **502-3**, **502-4**, and **502-5** disposed about LEDs **302-1** to **302-5**, respectively, in one or more embodiments of the present invention. Optical elements **502-1** to **502-5** may be asymmetrical spreading lenses arranged to avoid a spotty appearance by directing additional light into the spaces between LEDs **302-1** to **302-5** once leadframe assembly **202** is stretched out. Asymmetrical spreading lenses **502-1** to **502-5** may be bidirectional spreading lenses that direct additional light along the length of a stretched leadframe assembly **202** to mitigate dark regions between LEDs **302-1** to **302-5**. Bidirectional spreading lenses **502-1** to **502-5** may have the shape of two intersecting half parabolas.

Bidirectional spreading lens **502-1** directs more light in opposite directions along a spreading axis **504-1** than a null axis perpendicular to the spreading axis. Bidirectional spreading lens **502-1** is pre-rotated so spreading axis **504-1** would rotate and align along a desired direction, such as a "stretch" axis **606** (FIG. **6**A) along the length of a leadframe assembly **202** after the leadframe assembly **202** has been stretched (see FIG. **7**).

The amount of pre-rotation depends on the geometry of leadframe assembly **202**, including the interconnect pattern, the interconnect attachment points to the leadframes, and stretch hole locations, and the final length of the stretched leadframe assembly. For the geometry of leadframe **202** shown in FIG. **5**, spreading axis **504-1** is substantially parallel to a "pulling" axis **509** and pre-rotated about 45 degrees from a "row" axis **508** when leadframe assembly **202** is a typical square shape. Pulling axis **509** may be a line that passes through two stretch holes **214** and **220** along which leadframe assembly **202** is stretched after sacrificial ties **221** have been removed. Row axis **508** is a line that passes through LEDs **302-1** to **302-5** on leadframes **210-1** to **210-5** before leadframe assembly **202** is stretched.

However, spreading axis **504-1** may be angled relative to both pulling axis **509** and row axis **508** in other embodiments, depending on the geometry of the leadframe assembly **202** and the final length of the stretched leadframe assembly. In each embodiment the spreading axis is arranged to align along a desired direction after stretching the leadframe assembly in order to distribute light uniformly in a final product.

Bidirectional spreading lenses **502-2** to **502-5** are configured similarly to bidirectional spreading lens **502-1**.

FIG. **6**A shows a stretched leadframe assembly **602** in one or more embodiments of the present invention. In the stretched configuration, folded interconnects **212**, **216-1**, **216-2**, **216-3**, **216-4**, and **218** (FIG. 2A) are stretched to form substantially straight interconnects **612**, **616-1**, **616-2**, **616-3**, **616-4**, and **618**, respectively. Interconnect **612** is the unfolded, folded interconnect **212**, which includes vertical segment **212-1** (FIGS. **2**B and **2**C) and top folded section **232-1**. One end of interconnect **612** is connected to the anode of leadframe **210-1**.

Interconnect **616-1** is the unfolded, folded interconnect **216-1**, which includes bottom folded section **235-1**, vertical segment **236-1**, and top folded section **239-1** (FIG. **2**B). One end of interconnect **616-1** is connected to the cathode of leadframe **210-1** and the other end is connected to the anode of leadframe **210-2**. The other leadframes **210-2** to **210-5** are connected in a similar manner. Although folded interconnects **212**, **216-1** to **216-4**, and **218** are shown as substantially straight interconnects after stretching leadframe assembly **202**, interconnects **612**, **616-1** to **616-4**, and **618** may be slightly bent in some embodiments. In the alternative some portions of some interconnect segments may have kinks or lumps.

After stretching, LEDs **302-1** to **302-5** (only LEDs **302-1** to **302-3** with the accompanying lenses **502-1**, **502-2** and **502-3** are shown) are located along stretch axis **606**. As can be seen, spreading axis **504-1** of bidirectional spreading lens **502-1** is now aligned with stretch axis **606** along the length of leadframe assembly **602**. Bidirectional spreading lenses **502-2** to **502-5** are oriented in a similar manner as bidirectional spreading lens **502-1** so the bidirectional spreading lenses direct additional light from LEDs **302-1** to **302-5** along the length of leadframe assembly **602** to mitigate dark regions between the LEDs.

LED **302-4**, bidirectional lens **502-4**, LED **302-5**, and bidirectional lens **502-5** are omitted from FIG. **6**A to expose leadframes **210-4** and **210-5**. Leadframe **210-4** includes cathode pad **222-4** and anode pad **224-4** with wing areas **226-4** and **228-4**. Cathode pad **222-4** and anode pad **224-4** are electrically insulated from each other by a cutout or gap **225-4**. Once LED **302-4** (FIG. **5**) is mounted on cathode pad **222-4** and anode pad **224-4**, the pads are physically and electrically connected by the LED. Similarly leadframe **210-5** includes cathode pad **222-5** and anode pad **224-5** with wing areas **226-5** and **228-5**. Cathode pad **222-5** and anode pad **224-5** are electrically insulated from each other by a cutout or gap **225-5**. Once LED **302-5** (FIG. **5**) is mounted on cathode pad **222-5** and anode pad **224-5**, the pads are physically and electrically connected by the LED. FIG. **6**B shows that wing areas **226-4** and **228-4** of anode **224-4** are bent to form a mount **704-4** for leadframe **210-4**, and wing areas **226-5** and **228-5** of anode **224-5** are bent to form a mount **704-5** for leadframe **210-5** in one or more embodiments of the present invention.

FIG. **7**A shows an embodiment of a stretched leadframe assembly **702** oriented relative to reflectors **702-1**, **702-2**, **702-3**, **702-4**, and **702-5** in one or more embodiments of the present invention. Reflectors **702-1** to **702-5** are arranged to avoid a spotty appearance in the resulting tube light by reflecting light from LEDs **302-1** to **302-5** in a predetermined, uniform spread pattern to provide the appearance of a single, uniformly lit light source. Reflectors **702-1** to **702-5** also act as heat sinks to dissipate heat away from LEDs **302-1** to **302-5**.

Leadframe assembly **702** is arranged relative to reflectors **702-1** to **702-5** as follows. Reflectors **702-1** to **702-5** may be metal sheets that are at least partially curved. Adjacent reflectors are separated by a small gap. Interconnect **612** is suspended over part of reflector **702-1** and has its rightmost end connected to leadframe **210-1**. Leadframe **210-1** with LED **302-1** is mounted near the centroid of reflector **702-1**. Interconnect **616-1** is suspended over reflectors **702-1**, **702-2**, has its leftmost end connected to leadframe **210-1**, and has its rightmost end connected to leadframe **210-2**. Leadframe **210-2** with LED **302-2** is mounted near the centroid of reflector **702-2**. Interconnect **616-2** is suspended over reflectors **702-2**, **702-3**, has its leftmost end connected to leadframe **210-2**, and has its rightmost end connected to leadframe **210-3**. Leadframe **210-3** with LED **302-3** is mounted near the centroid of reflector **702-3**. Interconnect **616-3** is suspended over reflectors **702-3**, **702-4**, has its leftmost end connected to leadframe **210-3**, and has its rightmost end connected to leadframe **210-4**. Leadframe **210-4** with LED **302-4** is mounted near the centroid of reflector **702-4**. Interconnect **616-4** is suspended over reflectors **702-4**, **702-5**, has its leftmost end connected to leadframe **210-4**, and has its rightmost end connected to leadframe **210-5**. Leadframe **210-5** with LED **302-5** is mounted near the centroid of reflector **702-5**. Interconnect **618** is suspended over part of reflector **702-5** and has its leftmost end connected to leadframe **210-5**.

In FIG. **7**B, two sections consisting of leadframe **210-1**, LED **302-1**, reflector **702-1**, leadframe **210-2**, LED **302-2**, and reflector **702-2** are shown in one or more embodiments of the present invention. Wing areas **226-1** and **228-1** of anode **224-1** (FIGS. **2**B and **2**C) on leadframe **210-1** are bent to form a gull wing mount **704-1** that fixes leadframe **210-1** to reflector **702-1**. Mount **704-1** suspends one end of interconnects **612** and **616-1** above reflector **702-1**, thereby avoiding a possible short of interconnects **612** and **616-1** to reflector **702-1**. Wing areas **226-2** and **228-2** of anode **224-2** (FIGS. **2**B and **2**C) on leadframe **210-2** are bent to form a gull wing mount **704-2** that fixes leadframe **210-2** to reflector **702-2**. Mount **704-2** suspends one end of interconnects **616-1** and **616-2** above reflector **702-2**, thereby avoiding a possible short of interconnects **612** and **616-1** to reflector **702-1**. Other sections are similarly configured. Referring back to FIG. **7**A, insulating strips **706-1**, **706-2**, **706-3**, **706-4**, **706-5**, and **706-6** are provided along the length of reflectors **702-1** to **702-5** across the gap between adjacent reflectors to prevent a short between interconnects **612**, **616-1** to **616-4**, **618** and reflectors **702-1** to **702-5**. Insulating strip **706-1** is fixed under interconnect **612** and covers a left portion of reflector **702-1**. Insulating strip **706-2** is fixed under interconnects **616-1** and covers a right portion of reflector **702-1** and a left portion of reflector **702-2**. Insulating strips **706-3**, **706-4**, and **706-5** are configured similarly to insulating strip **706-2**. Insulating strip **706-6** is fixed under interconnect **618** and covers a right portion of reflector **702-5**.

Alternatively, as shown in FIG. **8**, insulating strips **808-1**, **808-2**, **808-3**, and **808-4**, are provided along the width of reflectors **702-1** to **702-5** along the gap between adjacent reflectors. Insulating strip **808-1** is fixed over the gap between reflectors **702-1** and **702-2**. Insulating strips **808-2** to **808-4** are configured similarly to insulating strip **808-1**. Once leadframe assembly **702** is fixed relative to reflectors **702-1** to **702-5**, they may be inserted into a tube lamp.

FIG. **9** is a top cutaway view of a tube lamp **900** in one or more embodiments of the present invention. When tube lamp **900** is applied as a LED retrofit tube lamp, it has the form factor of a standard straight fluorescent tube lamp. For this application, tube lamp **900** includes a transparent tube **902** (e.g., glass or plastic) and bi-pin connectors **904**A, **904**B mounted on the two ends of the transparent tube so the tube lamp can connect to standard fluorescent lighting fixtures. Tube lamp **900** may also include electronics to drive LEDs **302-1** to **302-*n*** (where n is a variable) from AC power. Tube lamp **900** may have other form factors depending on the application.

LEDs **302-1** to **302-*n*** on leadframes **210-1** to **210-*n*** are spaced with a horizontal pitch PHextended that is larger than horizontal pitch PHfolded (FIG. **3**). Horizontal pitch PHextended may be twice the size of horizontal pitch PHfolded or larger. With horizontal pitch PHextended of about 1 inch between LEDs **302-1** to **302-*n***, 47, 48 or 49 LEDs are required for a 4-foot long tube lamp **900**. Note that pitch PHextended varies depending on application.

A comparison between FIGS. **1** and **9** shows that tube lamp **900** uses a smaller number of LEDs than tube lamp **100**. As LEDs **302-1** to **302-*n*** are mounted on leadframe assembly **202**, they may use chip scale packaging to reduce the die size. Furthermore, leadframe assembly **202** uses less material than PCB **108**. As will be described later, the manufacturing of tube lamp **900** using leadframe assembly **202** can be efficiently performed on a large scale.

FIG. **10** is an exemplary flowchart of a method **1000** for manufacturing tube lamp **900** in one or more embodiments of the present invention. Method **1000** may include one or more operations, functions, or actions as illustrated by one or more blocks. Although the blocks are illustrated in a sequential order, these blocks may also be performed in parallel, and/or in a different order than those described herein. Also, the various blocks may be combined into fewer blocks, divided into additional blocks, and/or eliminated based upon the desired implementation. Method **1000** is explained with the help of the other figures showing progression through the method.

Method **1000** may begin in block **1002**. In block **1002**, a leadframe assembly is formed. The leadframe assembly is stamped or etched from a leadframe substrate such as a copper or aluminum sheet. Block **1002** may be followed by block **1004**.

In block **1004**, LEDs are mounted on the leadframes in the leadframe assembly. Solder paste may be applied to the cathode and the anode pads of the leadframes by screen printing. The LEDs are picked and placed onto the leadframes. The LEDs are then permanently soldered to the leadframes by solder reflow. Block **1004** may be followed by block **1006**.

In block **1006**, optical elements, such as bidirectional spreading lenses, are disposed about corresponding LEDs on the leadframe assemblies. Each bidirectional spreading lens is pre-rotated so its spread axis would rotate and align along a desired direction after the leadframe assembly is stretched. The amount of pre-rotation is determined according to the geometry of the leadframe assembly and the final length of the stretched leadframe assembly.

The bidirectional spreading lenses may be directly molded over the LEDs. Multiple bidirectional spreading lenses may be injection molded in parallel on the LEDs. The lens material may also serve to encapsulate exposed surface areas of the LEDs. Alternatively the bidirectional spreading lenses may be preformed, applied with adhesive, and picked and placed onto the LEDs. Block **1006** may be followed by block **1008**.

In block **1008**, the leadframe assembly is trimmed and formed. Specifically, the wing areas of the anode pads are bent to form the gull wing mounts, and sacrificial ties are severed to free the leadframe assembly from the leadframe substrate and the interconnects and the leadframes from each other. Block **1008** may be followed by block **1010**.

In block **1010**, the leadframe assembly is stretched. Block **1010** may be followed by block **1012**.

In block **1012**, the stretched leadframe assembly is fixed relative to reflectors with or without insulating strips. Block **1012** may be followed by block **1014**.

In block **1014**, the stretched leadframe assembly fixed to the reflectors is inserted into a transparent tube. Block **1014** may be followed by block **1016**.

In block **1016**, the terminal interconnects of the leadframe assembly are connected to electronics, which are connected to bi-pin connectors mounted to the ends of the glass tube.

Other types of optical elements may be used with the LEDs on a leadframe assembly. FIG. **11** shows a top view of leadframe assembly **202** with optical elements **1102-1**, **1102-2**, **1102-3**, **1102-4**, and **1102-5** that are reflector cups in one or more embodiments of the present invention. Reflector cup **1102-1** is disposed around LED **302-1**. Reflector cups **1102-2** to **1102-5** are configured similarly around LEDs **302-2** to **302-5**.

FIG. **12** shows reflector cup **1102-1** includes a set of planar sidewalls **1202**, **1204**, **1206**, and **1208** that are angled with respect to LED **302-1** to extract and direct light from the LED. Alternatively reflector cup **1102-1** has a curved surface centered about LED **302-1**. FIG. **13** shows an encapsulant **1302** may fill reflectors cups **1102-1** to **1102-5** to fix them to LEDs **302-1** to **302-5** and/or provide an index matching medium for the light emitted by the LEDs.

Reflector cups **1102-1** to **1102-5** may be directly molded on LEDs **302-1** to **302-5**. Reflector cups **1102-1** to **1102-5** may be injection molded in parallel around LEDs **302-1** to **302-5** on leadframe assembly **202**. Alternatively individual or a frame of reflector cups **1102-1** to **1102-5** may be preformed, applied with adhesive, and picked and placed around LEDs **302-1** to **302-5**. If a frame of reflector cups **1102-1** to **1102-5** is used, the reflector cups may be singulated as part of the trim and bend process in block **1008**.

Other types of leadframe assembly may be used for tube lamp **900**. FIG. **14** shows an isometric view of a leadframe assembly **1402** in one or more embodiments of the present invention. Leadframe assembly **1402** has three groups of linearly arranged leadframes. A left column of leadframes **1404-1** and **1404-2** is generally indicated by a phantom box **1405**, a middle column of leadframes **1406-1**, **1406-2**, and **1406-3** is generally indicated by a phantom box **1407**, and a right column of leadframes **1408-1** and **1408-2** is generally indicated by a phantom box **1409**. Leadframes **1406-1** to **1406-3** in middle column **1407** are staggered from leadframes **1404-1**, **1404-2** in left column **1405** and leadframes **1408-1**, **1408-2** in right column **1409**.

Leadframe **1404-1** includes a rectangular cathode pad **1410-1**, a rectangular anode pad **1412-1**, and a triangular wing **1414-1** extending inward from one edge of the anode pad. Leadframe **1404-2** is configured similarly to leadframe **1404-1**.

Leadframe **1406-1** includes a rectangular cathode pad **1416-1**, a rectangular anode pad **1418-1**, and triangular wings **1420-1**, **1422-1** extending from the two edges of the anode pad. Leadframes **1406-2** and **1406-3** are configured similarly to leadframe **1406-1**.

Leadframe **1408-1** includes a rectangular cathode pad **1424-1**, a rectangular anode pad **1426-1**, and a triangular wing **1428-1** extending inward from one edge of the anode pad. Leadframe **1408-2** is configured similarly to leadframe **1408-1**.

Wings **1414-1**, **1414-2** are interdigitated with wings **1420-1**, **1420-2**, **1420-3**, and wings **1428-1**, **1428-2** are interdigitated with wings **1422-1**, **1422-2**, and **1422-3**. Wings **1414-1**, **1414-2**, **1420-1** to **1420-3**, **1422-1** to **1422-3**, **1424-1**, and **1424-2** are later bent to form mounts.

An interconnect **1430-1** passes between wings **1414-1** and **1420-1** to connect cathode pad **1410-1** to anode pad **1418-1**. An interconnect **1432-1** passes between wings **1414-1** and

1420-2 to connect anode pad **1412-1** to cathode pad **1416-2**. An interconnect **1430-2** passes between wings **1414-2** and **1420-2** to connect cathode pad **1410-2** to anode pad **1418-2**. An interconnect **1432-2** passes between wings **1414-2** and **1420-3** to connect anode pad **1412-2** to cathode pad **1416-3**.

An interconnect **1434-1** passes between wings **1422-1** and **1428-1** to connect cathode pad **1424-1** to anode pad **1418-1**. An interconnect **1436-1** passes between wings **1428-1** and **1422-2** to connect anode pad **1426-1** to cathode pad **1416-2**. An interconnect **1434-2** passes between wings **1422-2** and **1428-2** to connect cathode pad **1424-2** to anode pad **1418-2**. An interconnect **1436-2** passes between wings **1428-2** and **1422-3** to connect anode pad **1426-2** to cathode pad **1416-3**.

As shown in FIG. **15**, LEDs **1502-1**, **1502-2**, **1502-3**, **1502-4**, **1502-5**, **1502-6**, and **1502-7** are soldered or otherwise fixed on leadframes **1404-1**, **1404-2**, **1406-1** to **1406-3**, **1408-1**, and **1408-2**, respectively. Optical elements **1504-1**, **1504-2**, **1504-3**, **1504-4**, **1504-5**, **1504-6**, and **1504-7** are then disposed on LEDs **1502-1** to **1502-7**, respectively. Each optical element may be a low dome lens (also known as a "batwing" lens) that spreads light in all directions to fill in areas between adjacent rows of LEDs **1502-1** to **1502-7**. Leadframe assembly **1402** is stretched in opposite directions along a stretch axis **1506** to space out LEDs **1502-1** to **1502-7** as shown in FIG. **16**. LEDs **1502-1** and **1502-2** are located in a left column **1605**, LEDs **1502-3** to **1502-5** are located in a middle column **1607**, and LEDs **1502-6** and **1502-7** are located in a right column **1609**. Stretched leadframe assembly **1602** may be fixed by mounts **1604** on reflectors and placed in a transparent tube of a tube lamp.

Anode **1418-1** (FIG. **14**) of LED **1502-3** is connected in parallel to cathodes **1410-1** and **1424-1** (FIG. **14**) of LEDs **1502-1** and **1502-6**, respectively. Anodes **1412-1** and **1426-1** (FIG. **14**) of LEDs **1502-1** and **1502-6**, respectively, are connected to cathode **1416-2** (FIG. **14**) of LED **1502-4**. Anode **1418-2** (FIG. **14**) of LED **1502-4** is connected in parallel to cathodes o**1410-2** and **1424-2** (FIG. **14**) of LEDs **1502-2** and **1502-7**, respectively. Anodes **1412-2** and **1426-2** (FIG. **14**) of LEDs **1502-2** and **1502-7**, respectively are connected to cathode **1416-3** (FIG. **14**) of LED **1502-5**.

Various other adaptations and combinations of features of the embodiments disclosed are within the scope of the invention. For example, tube lamp **900** may have the form factor of a standard circline or U-shape fluorescent tube lamp. As interconnects **212**, **216-1** to **216-4**, and **218** are flexible, a stretched leadframe assembly **602** may conform to the shape of the tube lamp. Instead of light-emitting diodes, other light sources such as lasers may be used. A large leadframe assembly may be constructed by combining leadframe assemblies **202** that are connected by cross bars in parallel. Each leadframe may have a single die attach pad for receiving a light source, which has bond pads connected by wire bonds to the corresponding interconnects. Numerous embodiments are encompassed by the following claims.

What is claimed is:

1. A solid state light-emitting device (LED) lighting apparatus, comprising:
- a stretched leadframe assembly, comprising:
  - leadframes spaced apart at a pitch, each leadframe comprising at least one pad;
  - interconnects each linking two adjacent leadframes;
  - LEDs mounted on the leadframes; and
- bidirectional spreading lenses disposed about the LEDs, each bidirectional spreading lens having a spreading axis and a null axis perpendicular to the spreading axis, each bidirectional spreading lens directing more light in opposite directions along the spreading axis than the null axis,
- the spreading axis being aligned along the length of the stretched leadframe assembly.

2. The apparatus of claim **1**, wherein the bidirectional spreading lenses comprise reflector cups around the LEDs and an encapsulant in the reflector cups.

3. The apparatus of claim **1**, further comprising one or more reflectors, the stretched leadframe assembly being fixed relative to the one or more reflectors.

4. The apparatus of claim **3**, further comprising insulating strips over gaps between adjacent reflectors.

5. The apparatus of claim **4**, wherein the insulating strips are provided along the length of the reflectors.

6. The apparatus of claim **4**, wherein the insulating strips are provided along the width of the reflectors.

7. The apparatus of claim **1**, wherein the LEDs are prepackaged light-emitting diodes or naked light-emitting diode dice.

8. The apparatus of claim **1**, wherein each leadframe comprises a cathode pad and an anode pad.

9. The apparatus of claim **8**, wherein the anode pad has wing areas bent to form a mount for the leadframe.

10. The apparatus of claim **1**, wherein the interconnects are substantially straight.

11. The apparatus of claim **1**, wherein the interconnects are slightly bent.

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